TAIYANGNEWS
ALL ABOUT SOLAR POWER

Heterojunction Solar Technology

2023 Edition

Working Hard on Cost Reduction

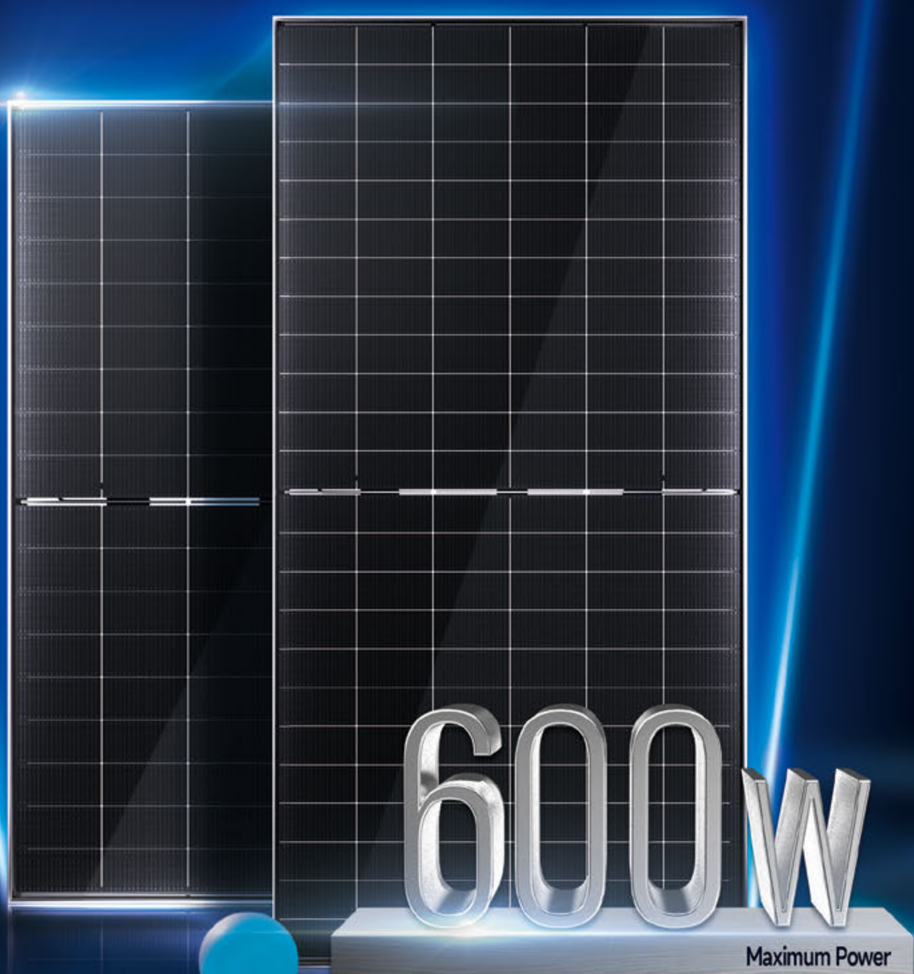
Authors: Shravan K. Chunduri, Michael Schmela

HUASUN | HETERO JUNCTION TECHNOLOGY

HJT 3.0

Himalaya G10 Series HJT Solar Module

- double side μc-Si
- SMBB Half-Cut Cell Technology
- Small chamfer
- Up to 85% Bifaciality



Contents

Heterojunction Solar Technology 2023 – Working Hard on Cost Reduction
ISBN 978-3-949046-16-2

Publisher:
TaiyangNews UG (haftungsbeschraenkt)
An der Golzheimer Heide 23
40468 Duesseldorf, Germany
www.taiyangnews.info

Advertisers:


risen
HJT
Choose RISEN ENERGY
Hyper-ion
Hyper-ion™
CONTACT US
risen
www.risenenergy.com

Executive Summary

The heterojunction segment has just seen something groundbreaking: LONGi has broken the efficiency world record Kaneka had held for 5 long years, and has created history in the process. At 26.81%, the efficiency figure achieved in Nov. 2022 is the highest reported so far for a crystalline silicon solar cell with an HJT-only cell structure. Notwithstanding HJT's potential that has become evident here, its relevance is insignificant from a commercialization standpoint.

However, the segment has seen several developments in the areas of optimization of device structure, process flow, and cost reduction that are very much relevant to real-time proaduction.

We last published an edition of TaiyangNews Report on Heterojunction Technology in August 2022, but some of the developments that have taken place since are quite noteworthy. To reflect these developments, a few of which were also presented on Day 2 of TaiyangNews Virtual Conference on High Efficiency Solar Technologies, we are now publishing a concise version of our HJT report.

There has been an interesting development related to HJT processing. The 3 main processing steps – annealing the wafers for gettering, cutting the wafers before cell processing, and light soaking –, which were under serious pursual, have now established themselves as part of the standard process at most of the HJT cell production lines. High wafer quality requirement for HJT is no more a prerequisite, as the annealing process addresses the issue of metallic impurities. Cell slicing reduces edge (cutting) losses. A point to be noted here is that all the subsequent cell and module production tools have been successfully optimized to handle half wafers without affecting the throughput. The light soaking process restores the performance losses of the HJT cells caused due to degradation during the initial period of module operation.

Reducing the thickness of the wafers is one of the most important wafer-related areas that can be targeted for cost reduction. Several companies have found that there is no performance loss even at a wafer thickness of 100 µm. At present, leading companies are at 130 µm and have plans to reduce the wafer thickness progressively. A price list from a leading wafer maker reveals that a 20 µm reduction in wafer thickness can compensate for most of the high prices associated with n-type wafers to make it comparable to p-type.

In the wet-chemical processing step – the first of cell processing – cleaning remains the key, in addition to optimization of texturing. While RCA and ozone are the 2 main cleaning options that manufacturers have relied on in the past, the latter seems to be the industry's choice of late keeping costs in view.

The most important development in the field of core layer deposition is the introduction of a doped microcrystalline silicon layer into the HJT structure, replacing amorphous silicon films, first on the front side and then on the rear. While this approach has been under evaluation, a few companies have already gone ahead and implemented it in production, at least on the front side, while they have a strategy in place for the rear as well. Production tools supporting this next generation of HJT cell structure are also supporting high throughputs of up to 7,200 wafers per hour.

When it comes to TCO, replacing indium has been a hot topic. While eliminating indium completely does not seem doable as of now, stacks of ITO and AZO can reduce the use of indium significantly, down to 85%. On the other hand, there is also an argument that "indium" is not a burning issue.

Most of the recent developments related to HJT are related to metallization. It also makes sense as silver used for forming the contacts dictates most of the cell conversion costs of HJT. Dual printing is the state of the art here. The industry was able to attain a significant reduction in paste laydown with SMBB, i.e., number of busbars beyond 12 or 15, 18 or even 24. The industry averaged about 18 mg of silver per watt in 2022, and the target is to lower it to 10 mg/W in 2023. Silver coated copper-based pastes are expected to play a vital role in further reducing silver consumption. Getting rid of busbars from the cell surface is also part of the plan. Interestingly, a few companies are of the opinion that plating is going to play an important role in cost reduction as well as performance improvement of HJT in the near future.

Within module making, more than the process, it is the materials that are the subject of innovation. Leading encapsulation material suppliers have introduced light conversion films that can convert UV light into red or blue band, which enhances the absorption with HJT in particular and results in a power gain. The industrial cell efficiencies in China have surpassed 25% in general, while the specifics vary from one case to the other. An increasing number of module products based on HJT are entering the commercial space. Today's market offers HJT modules for all applications, including 700 W products for the utility scale. This report also provides an overview on the status of commercialization, capacity, and costs.

Enjoy reading our report on Heterojunction Solar Technology 2023

Shravan K. Chunduri
Head of Technology, TaiyangNews
shravan.chunduri@taiyangnews.info
+91 996 327 0005
Hyderabad, India

Michael Schmela
Managing Director, TaiyangNews
michael.schmela@taiyangnews.info
+49 173 15 70 999
Duesseldorf, Germany

1. Introduction

The cost-performance ratio – the ultimate performance metric of a PV device – can be improved in several ways. The first and most sorted method is to improve the electrical parameters of the PV device to make it more sensitive to the incident sunlight; in other words, efficiency. The incumbent PERC cell technology can only support efficiencies up to 21.7%, as indicated by the monthly TaiyangNews Top Solar Modules listing available on our website (please see the latest editions HERE). To achieve higher efficiencies beyond this level, high efficiency cell architectures such as TOPCon, heterojunction (HJT), or interdigitated back contact (IBC) structures are typically used.

IBC still remains somewhat exclusive to only a handful of companies. TOPCon, on the other hand, has largely been recognized as the natural successor to PERC, with several prominent PV manufacturers entering mass production and planning gigantic expansions with the technology. Still, several noteworthy developments are taking place in parallel with respect to HJT as well.

First and foremost is the progress in efficiency. HJT has been regarded as the platform for attaining higher efficiencies, and several HJT producers have achieved 25% and above. However, something spectacular has been recently reported in this context. Kaneka's HBC structure (a fusion of HJT and IBC) held the record for the highest crystalline silicon cell efficiency at 26.63% until November 2022. The world's largest PV manufacturer, LONGi, has now pushed it to the next level, creating history by surpassing a record held for 5 years, with the highest reported efficiency of 26.81%. LONGi created this record on an "HJT only" platform, meaning it is not a back-contact architecture, but purely based on HJT with contacts on both sides.

Not as eye catching, but HJT technology has seen several incremental improvements, including optimization of device structure, process flow, and cost reduction. One significant development in cell architecture optimization has been the replacement of doped amorphous silicon layers with microcrystalline films. The process flow

Source: Huasun

Still relevant: Even as TOPCon is being touted as the natural successor to PERC, HJT continues to attract considerable interest.

has been further improved with the inclusion of wafer annealing and light soaking, which are now standard practice. Moreover, newly built factories are increasingly implementing the cutting of wafers beforehand. Cost reduction has become a top priority, with the industry pursuing new ways to reduce silver paste consumption, and this has also given rise to alternative metallization solutions such as plating. Transparent conductive oxides (TCO) are also being developed, which can significantly reduce indium consumption. Also, a few optimizations have been made at the module level to improve overall performance. Companies like Risen are also promoting HJT technology for a low carbon footprint.

The field of heterojunction technology has seen numerous advancements and improvements in recent years, many of which were discussed in the 3 reports TaiyangNews has published on this topic, the most recent published in August 2022. Since then, however, there has been considerable amount of progress made in various aspects of the technology. The latest updates were exclusively presented and discussed on Day 2 of the TaiyangNews Virtual Conference on High Efficiency Solar Technologies, which dealt with HJT (see presentations here). This TaiyangNews report is highlighting the latest major advancements that have taken place in the HJT segment over the last 6 months.

HJT stands out with several unique attributes. At the cell level, the technology follows a fairly different process flow than PERC and TOPCon, thus requiring special tools and process consumables. It also requires considerable optimization at the module making stage. All previous HJT reports published by TaiyangNews have comprehensively covered the fundamentals of the technology along with the implications on supply and value chains of HJT. This edition directly jumps to the latest developments starting with cell processing.

Source: GS-Solar

Different setup: HJT employs a distinctive process flow, which necessitates a different set of tools on the production line, with PECVD and PVD being crucial tool set.


MAKING IT HAPPEN
DKEM® METALLIZATION SOLUTIONS
FOR HJT SOLAR CELLS
SILVER PASTE SOLUTION
DK61A/DK51A Ag pastes designed for ultra-fine line printing to boost efficiency while achieve significant laydown saving
SILVER-COATED COPPER PASTE SOLUTION
DK51F/DK61F AgCu pastes delivering remarkable cost-saving while maintain good efficiency and reliability
When Performance Matters
EMPOWERING A BRIGHT NET-ZERO FUTURE

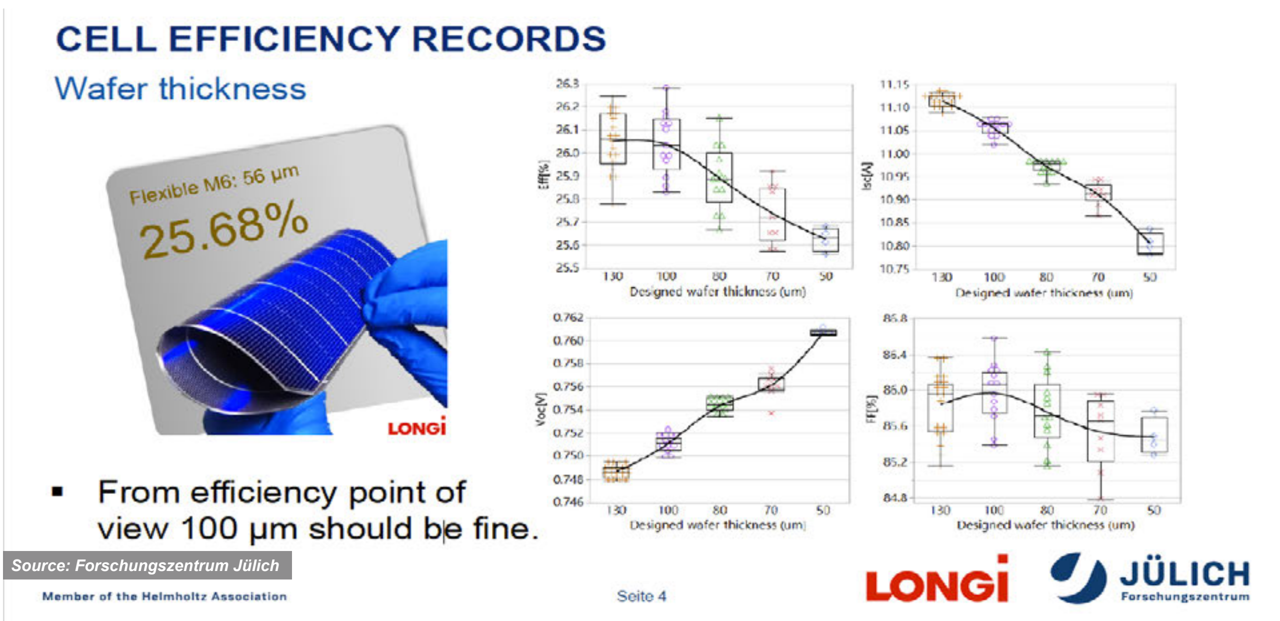
2. HJT Cell Processing

HJT has been promoted as a technology with fewer processing steps – typically 5 in number – and these process steps also differ significantly from the mainstream PERC or even TOPCon. After the silicon wafers are etched to remove saw damage and textured, intrinsic amorphous silicon layers are applied to both sides, followed by doped amorphous silicon films with opposite polarities. Next, a TCO film is applied to act as an antireflective coating and conductive electrode for current extraction. Most HJT cells today are bifacial, with TCO deposited on both sides. Alternatively, a full-area metal film may be applied to the rear side to make the cell monofacial. A metallic grid is then screen-printed on top of the TCO and cured to produce the HJT cell. Finally, the cells are tested and sorted.

An interesting development with regard to the process sequence is that 3 additional steps are increasingly becoming part of the standard process sequence – annealing of wafers for gettering, cutting the wafers before the cell processing, and light soaking. The first 2 steps take place before the start of cell processing, as they are related to wafers. In fact, the change required for HJT starts at the wafer level.

2.1. Incoming Wafer Supply

One of the most significant wafer-related developments is half cell processing, which is becoming inevitable in the case of larger wafer formats. As discussed in the 3rd edition of our HJT reports, the HJT segment, especially its entire production tool supply stream, though late, has successfully adapted to processing larger wafers. Cutting of the cells is becoming a necessary step in order to counter resistance losses. On the other hand, the edge losses for HJT based on larger wafers, when processed into complete cells and then sliced, are higher compared to PERC due to the damages to TCO and also at the sliced edges. To address this problem, the equipment supply chain is now facilitating the processing of half wafers for HJT, meaning the wafer is sliced into half before cell processing, and these slices are then processed into cells. This approach brings in another benefit, which is the ability to process thinner wafers. As one could imagine, in the case of very thin and full wafers, the occurrence of wafer bending could be high. This can be avoided by cutting the wafer beforehand. At the line level, it is also easy for the automation to handle half-cut thin wafers compared to thin-full slices. These benefits are increasingly becoming hard to



Source: Forschungszentrum Jülich

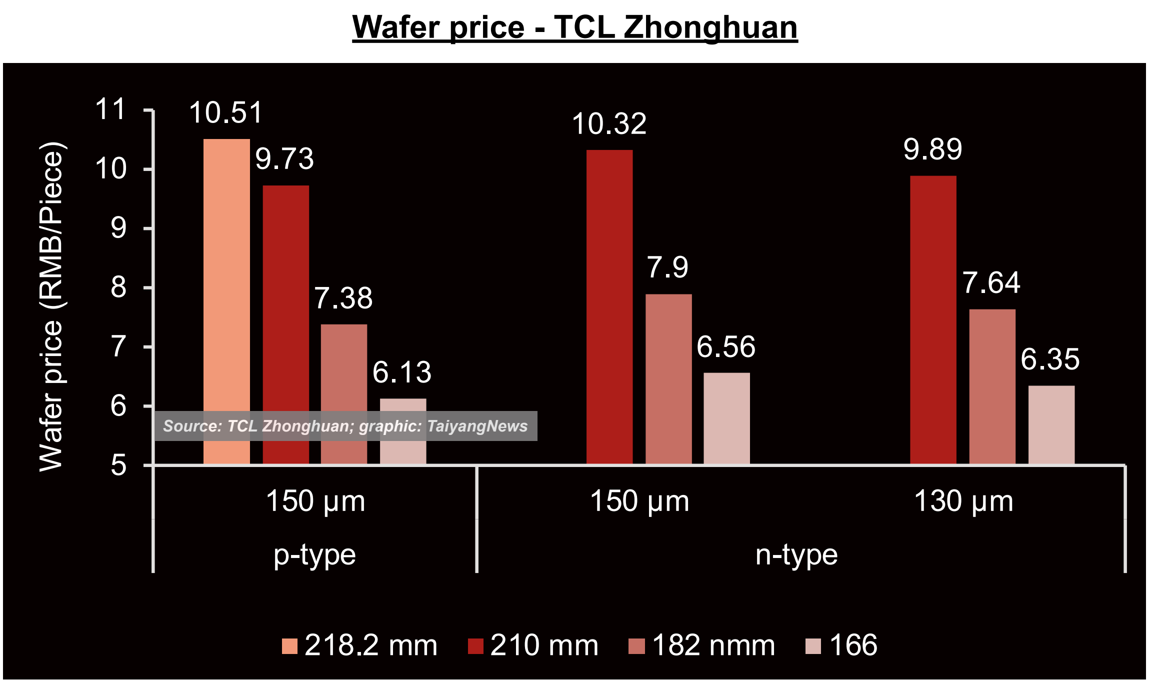
Slimmer is better: With its symmetrical cell structure, HJT supports thin wafer processing. While the industry is already at 130 µm, there is a clear path toward 100 µm and less.

ignore, thus, it is now becoming part of the standard practice.

This is also the same with pre-annealing. In order to overcome the requirement for high wafer quality, the industry has adopted a heat treatment process (annealing) that mimics gettering, a process of removing metallic impurities with thermal treatment. As a result, HJT can now use wafers from different positions of the ingot and production runs of the crucible. Gettering also helps increase the yield of the whole line, according to Peter Wolf, VP overseas sales at the leading HJT tool vendor Maxwell. Thus, the heat treatment step is also becoming part of the process flow at leading production lines of HJT.

A very important wafer related topic for HJT is thickness reduction. This cell structure is highly compatible with thinner wafers, and its unique symmetrical structure only adds up to this benefit. **Po-Chuan Yang**, **general manager at Risen Energy's Business Unit HJT**, shared the company's experience in its journey towards thinner wafers in its **presentation Progress on HJT Technology and Key Milestones at Risen** (**see presentation** here) during our TaiyangNews High Efficiency Solar Technologies 2022 event in Nov. 2022. Risen reduced the thickness in progressive steps of 10 µm, starting at 150 µm. However, each new step took longer than the previous one as several issues needed addressing, not only in cell production, but also in modules. For example, it took several weeks to hit 140 µm from 150 µm, a few months for the next 10 µm reduction and about half a year from then on to reach 120 µm. The company says that it now has a clear path towards 80 µm and is confident that it will enter mass production in the near future. In the meantime, Risen has already put 120 µm into production.

At the TaiyangNews HJT event, **R&D director of solar cells at Huasun, Su Zhou** shared his insights into wafer thickness reduction potential with respect to efficiency in his talk on **Mass Production Status and Future Trends of HJT Solar Cells** (see presentation here). The cell efficiency does not change notably while moving from 140 µm to 100 µm, according to Zhou. He further emphasized that the industrial goal for wafer thickness would be about 90 to 100 µm. Huasun has also started a wafer cutting facility and, according to Zhou, after several months of mass production experience, the equipment, material and process are now ready for 120 µm and 130 µm. On the 100 µm front, a cutting yield of 90% has been reached in the R&D line of Huasun's cutting lab, he said.



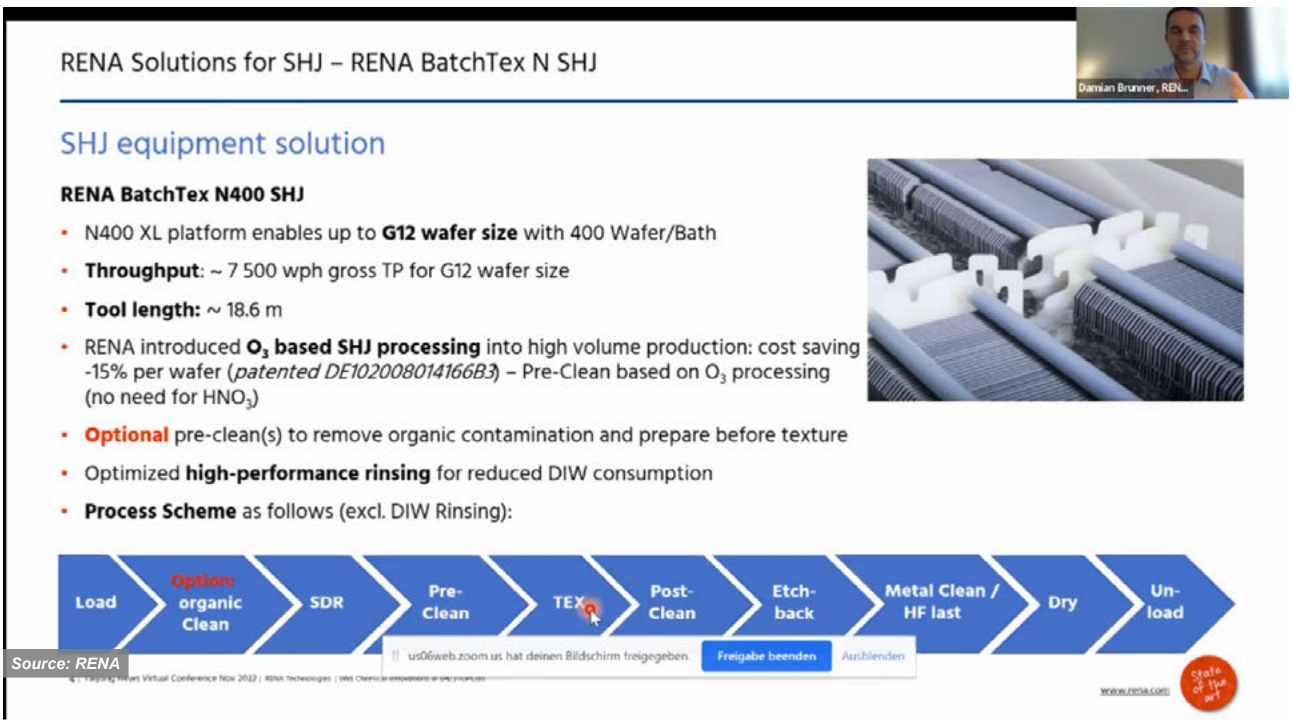
Price parity: The premium for n-type can more or less be compensated with about a 20 µm reduction in wafer thickness, as shown in this price list from TCL Zhonghuan from November 28, 2023.

Kaining Ding, head of R&D department at the German research center Forschungszentrum Jülich (FZJ), in his conference keynote on the Status of HJT said that the mainstream wafer thickness was about 150 µm (during the end of 2022) and it is likely to go down to 125 µm; however, 100 µm is sufficient to achieve a cell efficiency of >26% (**see presentation here**). The main motivation behind reducing the wafer thickness is cost. To quantify the benefits, while it may not be absolutely accurate, a wafer price list from TCL Zhonghuan released in November 2022 offered some direction (see graph on p. ##). It is public knowledge that n-type wafers are more expensive than p-type, and this price list indicates that the difference was about 6% at the time. This was determined by comparing the prices of n-type and p-type wafers of the same size (210 mm) and thickness (150 µm), given as 10.32 RMB and 9.73 RMB per piece, respectively. It is obvious that reducing wafer thickness reduces costs and enables companies to reduce prices as well. Again, this price list indicates that a 20 µm reduction in wafer thickness results in savings of 4.3% on wafer price, as indicated by the price of 210 mm wafers of 150 µm (10.32 RMB) and 130 µm (9.89 RMB). Thus, it is safe to say that if the n-type cell technologies can support a wafer that is 20 µm thinner, extra costs from the wafer side can be brushed off as negligible. The good news is that HJT, as it is, is able support this thickness delta with huge potential for slimming it down further.

2.2. Wet-Chemical Processing

As with standard cell making, the HJT process also starts with saw damage etching (SDE), followed by texturization and cleaning. All these steps are individually optimized for HJT. The typical PERC process flow avoids SDE, while it is highly relevant for HJT, emphasized **Damian Brunner, senior R&D manager solar & battery at RENA in his talk on Wet Chemical Innovations in SHJ & TOPCon Cell Processing (see presentation here)**. RENA is offering an organic cleaning option before the SDE step, which can be either ozone based or hydrogen peroxide, while the latter is recommended when a high degree of cleaning is required. SDE is alkali-based, and the process intensity strongly depends on the quality of the incoming wafer.

The preconditioning process before texturing facilitates homogeneity in pyramid distribution and helps adapt to the height of the pyramids formed in



Source: RENA

Cleaning is key: The major change with respect to wet-processing for HJT is cleaning, as shown here in the slide from RENA at the TaiyangNews High Efficiency Solar Technologies Conference; ozone-based cleaning is becoming the standard.

texturing. This is very important as, after texturing, the surface morphology strongly influences the quality of the passivation. In the post-texturing step, rinsing and cleaning are crucial.

Overall, cleaning is the most important change required for HJT at the wet-chemical station. HJT demands a specific cleaning regime to remove organic and metallic impurities. The quality of the deposition – and thus the ultimate passivation – strongly depends on the cleanliness of the wafers, especially since the HJT process is carried out at low temperatures. There are 2 cleaning methods that are largely followed – an ozone-based process and a so-called RCA process using hydrogen peroxide. While RCA is effective as well as robust, it is also expensive, not only due to the high price of the chemicals of which hydrogen peroxide is at the top, the effluent treatment costs are also high. For this reason, ozone-based cleaning is attracting a lot of attention. As a matter of fact, none of this is new, except that ozone-based cleaning is becoming the mainstream.

RENA, for example, uses ozone-based preconditioning and cleaning before SDE, as mentioned above, followed by pre-cleaning before texturing. In post-texturing, the first cleaning step is also based on ozone to get rid of organic residues, and the process ends with ozone-based etch-back and HF-based metal cleaning.

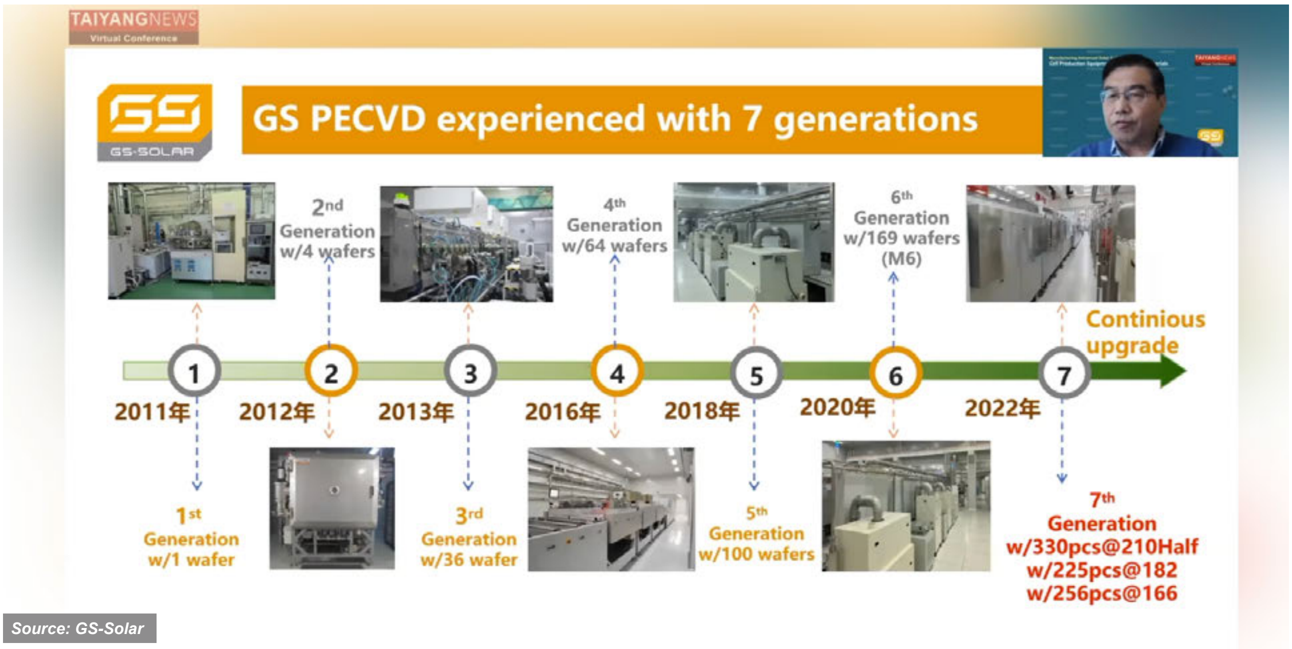
At the tool level, most of the leading wet-chemical bench suppliers are offering production tools that can support high throughput of around 7,000 wafers per hour integrating all the above discussed functionalities. The equipment is also designed to support half-wafer processing.

2.3 Core Layer Deposition

After the wet-chemical treatment, the wafers enter the core layer deposition stage, which is the heart of HJT processing. It involves multi-layer stacking of intrinsic-amorphous followed by doped-amorphous silicon layers of opposite polarities on each side of the wafer and controlling them at the nanometer scale. This is very important as the junction is created at the surface, and the deposited layers also dictate the effectiveness of passivation, which is key for HJT's high performance. Not only in terms of performance, as much as half of the CapEx required for the entire HJT cell processing line can be attributed to the core layer deposition tools. The importance and fundamentals of core layer deposition were discussed in depth in the previous editions of our HJT report; and as in the past, PECVD technology is still the state of the art for core layer deposition.

The most important development in the field of core layer deposition is the introduction of a microcrystalline silicon layer into the HJT structure. Implementing microcrystalline in the industry only refers to replacing the doped amorphous silicon layers, while the very thin intrinsic amorphous silicon films of 1 to 2 nm attached to the wafer surface remain the same. The primary advantage of using n-type microcrystalline silicon on the emitter side is that it can improve the current (Isc) and fill factor (FF). The increase in Isc is due to the fact that the light absorption coefficient of the microcrystalline silicon is far less than amorphous silicon. HJT devices that use microcrystalline silicon exhibit superior short and long wavelength responses. Risen says it will also introduce oxygen or carbon to increase the band gap within the microcrystalline layer for better short wavelength responses. The increase in FF is mainly due to the superior conductivity of the microcrystalline film, which decreases the silver resistance of cells and reduces the dependence on ITO for conductivity. The industry is also evaluating replacing p-type amorphous silicon with microcrystalline silicon on the rear side as the next step of improvement. Using a microcrystalline doped layer on both sides leads to high field effect passivation. The industry is colloquially referring to the amorphous silicon on both sides as HJT1.0, microcrystalline on the emitter side as HJT2.0, and double-sided microcrystalline as HJT3.0.

At TaiyangNews' recent Solar Cell Production Equipment & Processing Materials conference (end-February), Jinyan Zhang, the GM at R&D department for GS-Solar, gave an insightful presentation on their specific PECVD solution for depositing microcrystalline silicon, titled "Development of Micro-Crystalline HJT Solar Cells using 13.56MHz RF Mass Production Equipment" (see recording here). Zhang emphasized that the 13.56MHz RF technology is ideal for large chamber PECVD equipment used in mass production of microcrystalline HJT cells, citing benefits such as



Source: GS-Solar

Generations of progress: GS-Solar is now offering a 7th gen PECVD tool that not only supports application of microcrystalline silicon, but also supports high production capacity between 800 MW and 1 GW, as shown by GS-Solar R&D GM Jinyan Zhang at a TaiyangNews Conference.

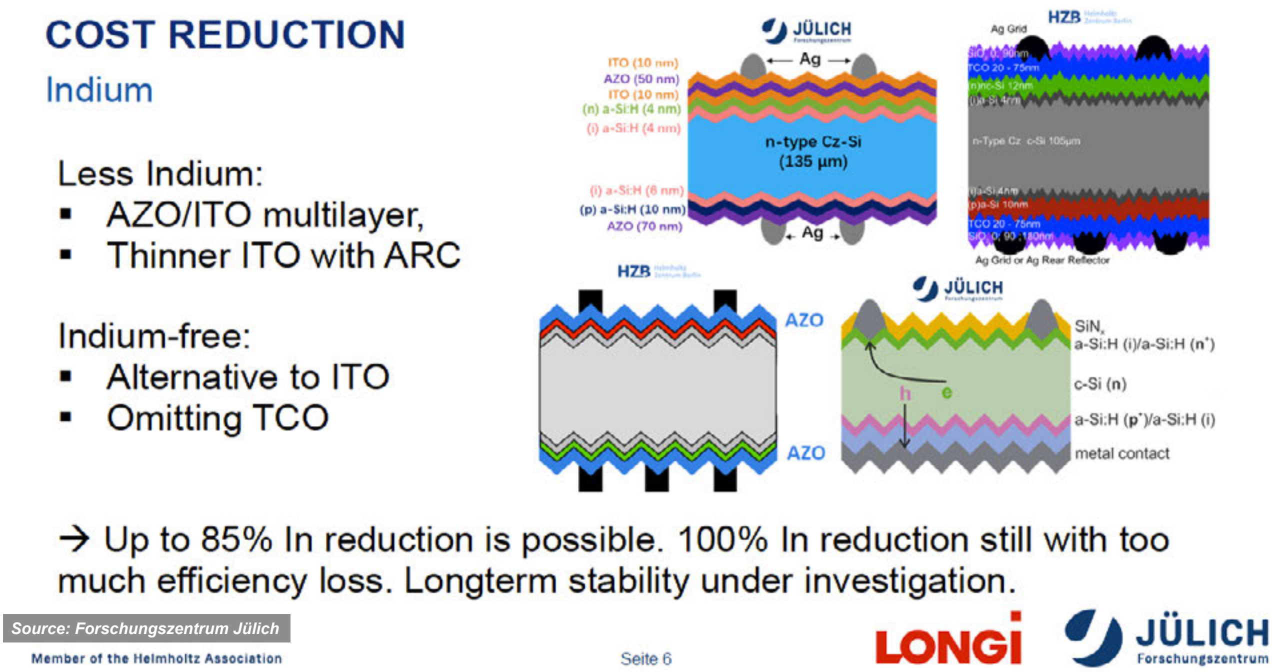
good uniformity of the deposited films, a relatively wider and tolerant process window, and no plasma damage. He also presented raw production data that showed significant efficiency gains; a 0.5% efficiency gain with n-type microcrystalline silicon on emitter leading to an absolute efficiency of 24.47% and a further 0.4% gain by using the microcrystalline films on both sides that led to the efficiency of 25.45%. GS-Solar's latest 7th generation PECVD reactor has a capacity of 800 MW to 1 GW per single tool, and is capable of processing 330 half pieces of G12 wafers, a significant improvement over the previous generation tool's ability to process only 169 M6 wafers.

Maxwell, Ideal Energy Sunflower, and H2GEMINI are the other key tool suppliers in this segment. The PECVD tools from all these companies are able to support processing up to G12 size as well as half wafers, in addition to supporting higher throughputs of over 6,000 wafers of the same format. Among these, Maxwell's tool supports the highest level of 7,200 wafers per hour. Wolf also presented the important features of the company's PECVD tools in his **High Efficiency & Low Cost HJT Turnkey Line Solution** talk at the TaiyangNews Conference **(see presentation here)**. Top of the list is that the company uses 3 pieces of PECVD tools instead of the typically used 2. "We do i, i-n and p instead of typical i-n and i-p in 2 reactors," said Wolf, where i stands for intrinsic and n & p denote the 2 polarities of doping. This approach has 3 key benefits according to Wolf. The first is that the tray is not shared between i and p, which avoids boron-related contamination, thereby resulting in better passivation effect. Since the intrinsic layers are deposited first on both sides, the junction interface is protected while also avoiding phosphorus-related contamination on the p-side during the i-n coating. Finally, it also facilitates relatively higher i-layer deposition temperatures, improving the quality of the film.

2.4 TCO Deposition

The second half of deposition in HJT processing deals with the application of the TCO layer, which acts as both an antireflective coating and a conductive electrode to extract and laterally conduct the electrical current.

Applying TCO is also a very important step in HJT processing. Here, enough care must be taken to retain the passivation properties of the underlying amorphous silicon layers. The quality of the TCO influences lateral charge collection. In addition, the transparency and resistivity of the TCO are also very important. The application is typically accomplished



Elephant in the room: The industry has been evaluating various options to eliminate or reduce indium. While eliminating is not an option yet, it can be reduced by 85%.

in PVD tools by means of sputtering, and indium tin oxide (ITO) is the most commonly used material. Reactive Plasma Deposition (RPD) is an alternative method, but it is yet to enter mainstream commercial production.

The hot topic in the TCO segment is how to reduce indium consumption – the key ingredient of ITO – if not eliminate it altogether. The fact that indium is only second to silver in terms of non-silicon costs of HJT cell production is what puts it in focus. Its limited availability is another issue. Aluminum-doped zinc oxide is becoming an effective alternative. It is low cost and non-toxic, but it is a relatively less inert material chemically. However, eliminating indium does not seem possible, at least as of now, according to FZJ's Ding. Cells based on indium-free TCO suffer from high level of efficiency losses, whereas Ding emphasizes that indium consumption can be reduced by 85% through the use of a stack of AZO/ITO. Approaches such as using thinner ITO with ARC are also under evaluation. This helps move the spotlight away from indium consumption issues for some time at least.

Touching a bit on the equipment side while on the topic, Maxwell's Wolf said that his company's tool platform is ready with a solution, underlining "we don't see a shortage at the moment." However, to be future ready in case such a need arises, Maxwell's PVD can already use AZO and apply coatings as stacks starting with ITO; 2 layers of AZO and then ITO on top, for example.

Optimization for better target utilization has remained an important topic on the tool vendors' end. However, the major focus in optimization at an equipment level after ITO consumption is higher throughput. There are more PVD vendors compared to PECVD, including Von Ardenne, Singulus, Maxwell, S.C New Energy, GS-Solar and H2GEMINI. Among these, Germany's Von Ardenne has the highest throughput of 7,500 wafers per hour, followed by Maxwell at 7,200. In order to support this high throughput, Maxwell, for example, is integrating more processing units – 4 on top and 4 on the bottom. Ease of operation and maintenance without the need for industrial line cranes is also a common attribute of the PVD tools from leading suppliers.

2.5. Metallization

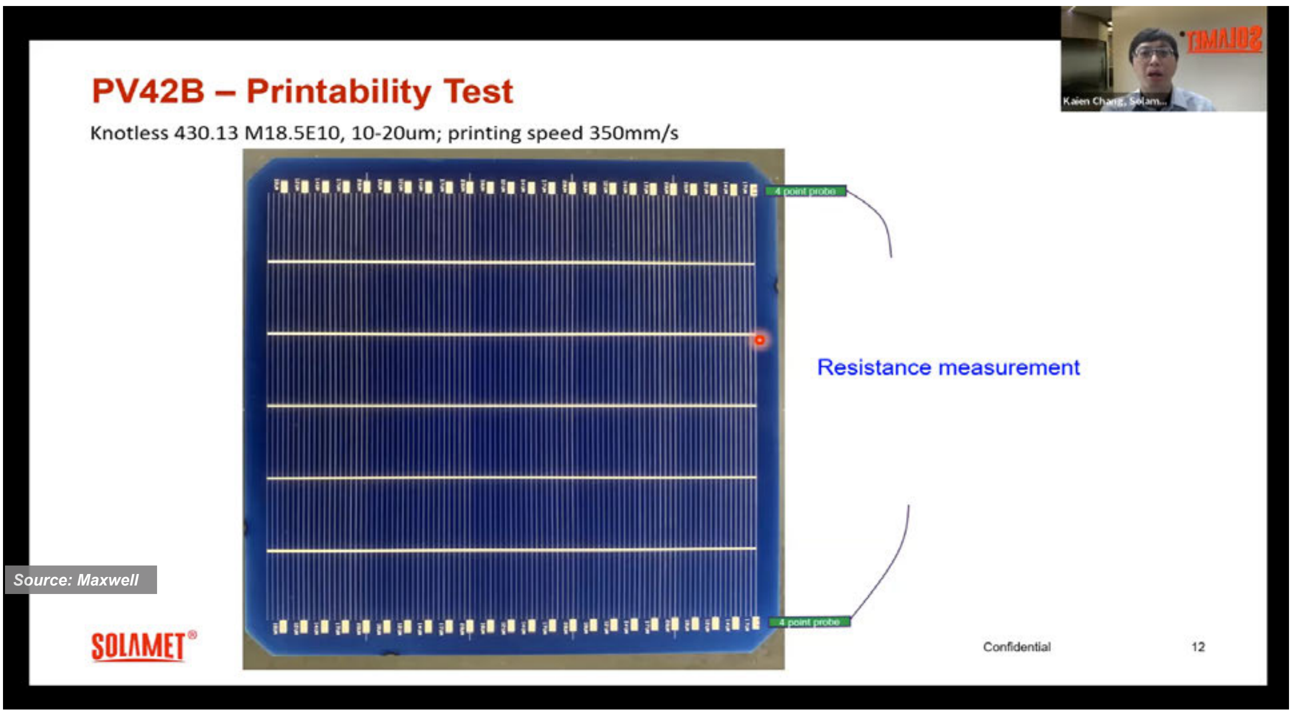
Metallization has attracted utmost attention in terms of developments among all the HJT process stations. That's understandable, as one of the major bottlenecks for HJT currently is its much higher cost, both in terms of CapEx as well as

OpEx. Also, metallization paste governs the major chunk of processing costs for HJT. The process for HJT is very different to the mainstream. While the method of metallization is still screen-printing, the paste systems used for other cell architectures are typically fired at temperatures above 700 °C. In case of HJT, the amorphous thin films employed are hydrogenated. Given hydrogen’s tendency to escape at higher temperatures, the paste system must work at low temperatures of about 200 °C to avoid poor passivation. This calls for the use of special silver pastes that can be cured at low temperatures.

2.5.1. Screen-printing

Such silver pastes are loaded with silver into thermoplastic polymer systems and come with a few inherent limitations, like long processing times and higher resistance. The latter leads to a high paste laydown to keep the conductivity consistent. Kaien Chang, vice president of technology at Solamet presented the company's low temperature paste solutions for HJT at TaiyangNews conference. Solamet is a Chinese paste supplier named after the former metallization paste brand of DuPont that acquired all metallization assets from DuPont, including intellectual property and workforce. In his talk, Novel Low Temperature Paste Development for HJT and Perovskite Tandem Cells (see presentation here), Chang discussed the pain points associated with the low temperature epoxy-based pates for HJT, such as low printing speed of 200 to 250 mm/s compared to PERC's 400 mm/s, resulting in lower throughput. Additionally, HJT has issues with fine line printing, with typical screen openings of 20 to 24 µm compared to PERC's 12 to 15 µm, leading to a higher laydown of 18 to 23 mg/W versus PERC's 8 to 11 mg/W. Solamet has developed a new paste called PV42B, which addresses these challenges and supports fine line printability with low laydown.

Solamet's latest paste product has been designed without the typical larger flakes of silver used in epoxy pastes. This composition improves paste transfer, enabling fine line printability and ultimately resulting in low laydown. The absence of larger silver flakes also improves contact to TCO. Chang presented results of an in-house designed printability test with a single screen having multiple openings ranging from 10 to 20 µm, which showed that at a printing speed of 350 mm/s, the PV42B matched the printability of PERC paste with no disruptions to line quality. The paste also supports low laydown.



Source: Maxwell

Interesting test: At the TaiyangNews High Efficiency Solar Technology 2022 Conference, Solamet presented the results of an in-house printability test using a screen with 10 to 20 µm openings, allowing for fine line printability testing of pastes.

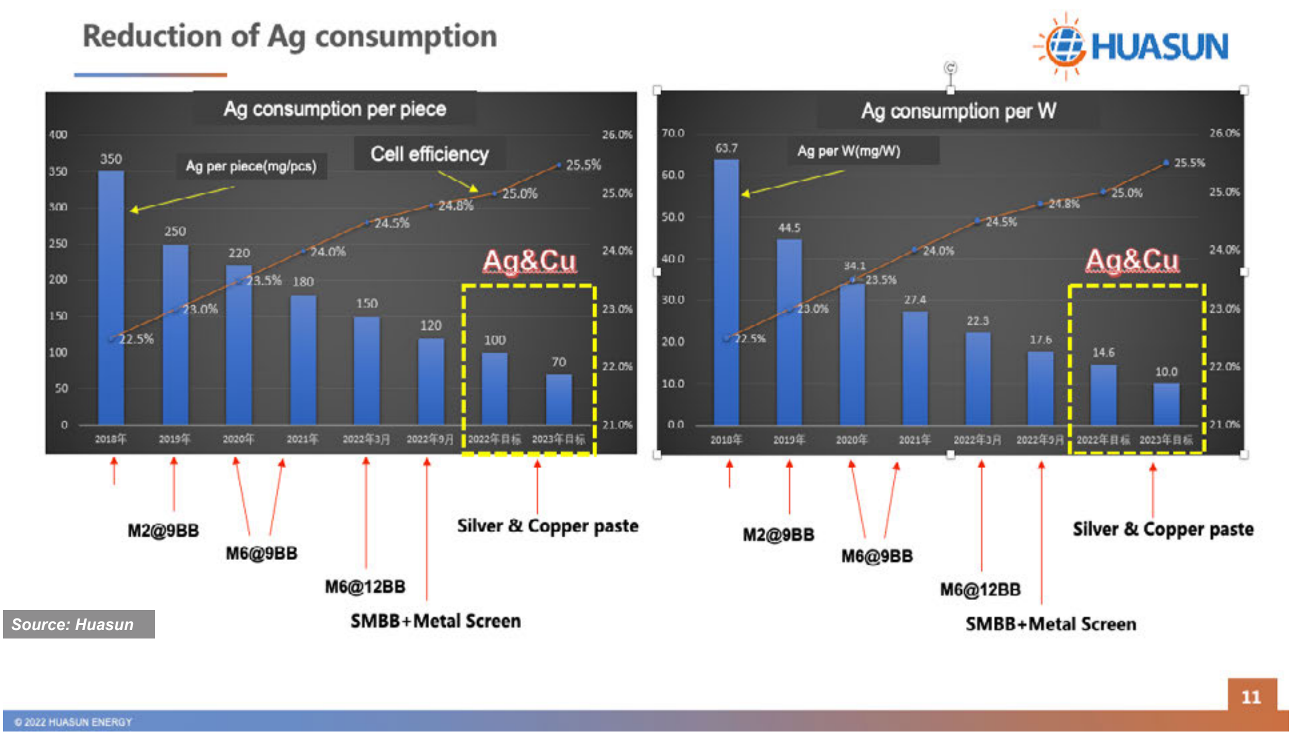
Solamet also offers another low temperature paste, PV43B, for perovskites tandem cells, which can be processed at even lower temperatures down to 120°C.

When it comes to printing technology, dual printing is the state of the art as it favors low paste laydown. Increasing the number of busbars has proved to be an effective means of reducing paste consumption. While the 12-busbar layout has already been implemented, a few products based on 15 busbars are available, and a few are planning to go beyond 18 or even 24. Silver consumption has been significantly reduced in the industry, and more so in 2022, from 180 mg per M6 wafer to 120 mg. This has been achieved by using SMBB (super MBB, which is nothing but more busbars) and a metal screen, according to Huasun's Zhou. FZJ's Ding puts it at 18 mg/W for G12 wafers with dual printing and more busbars. Huasun's silver consumption was at 14.6 mg/W at the end of 2022 and is expected to decrease to 10 mg/W during 2023.

A noteworthy development with regard to reducing silver usage is the use of paste systems consisting of copper particles that are coated with silver, instead of using pure silver suspension. This directly reduces silver consumption, and thereby costs, albeit not proportionately as the process of coating copper with silver is not cheap.

Zhou shared Huasun's experiences with silver coated copper. The company was using such pastes only on the rear side and just for the fingers, at least end of 2022, because the majority of these pastes are not fully optimized for the front side. Using silver coated copper on the rear side only for fingers, a saving of 24 mg of silver per cell has been achieved, down from 126 mg per M6 wafer to 102 mg. As to the performance, this novel paste material has led to a slight efficiency loss of 0.03% absolute, which is negligible. However, employing these pastes on the front side leads to a considerable dip in efficiency, according to Zhou. The next step for the company is to try silver coated copper paste for busbars and also for frontside fingers with paste formulations optimized for these applications. "Our target is to reach a silver consumption of 70 mg/wafer with silver coated copper," said Zhou.

Reliability is the next area of concern with silver coated copper. "Copper leakage and oxidation of



Source: Huasun

Saving on silver: At TaiyangNews' HJT event, Huasun presented the developments in metallization to reduce silver consumption.

the copper" are the 2 examples quoted by Ding in this regard. However, Huasun's Zhou said that his company has evaluated the reliability of silver coated copper to conclude that it would not affect the long-term stability of the module.

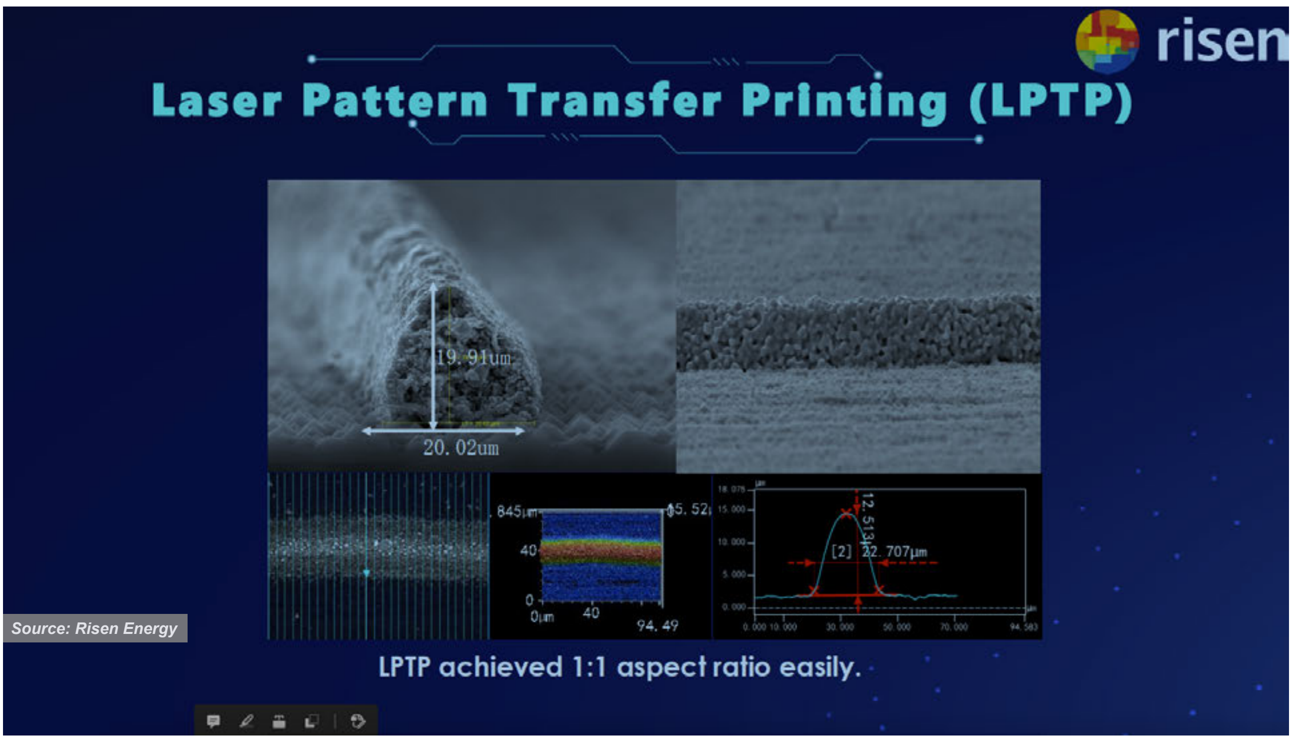
There are several other approaches being pursued to reduce silver consumption. Eliminating busbars is another example. Typically, 25% to 30% of the paste applied on the cells is used for busbars. For example, out of a total laydown of 126 mg of paste per an M6 cell, close to 40 mg is used for busbar formation. The busbar-less cell design first relates to the SmartWire Connection Technology (SWCT), a proprietary interconnection method that enables interconnects to be directly attached to the fingers, eliminating the need for busbars. The technology is protected with IP, and Meyer Burger has withdrawn the solution from the open market. However, MBB also supports a busbar-less cell design. Risen says that its cells that support 24 busbars are based on a no-busbar design, which comes with its own set of challenges in module making. On top, rumor has it that an indigenous technology is also under development in China, while no further details are available.

2.5.2. Alternative Metallization Approaches

Laser Pattern Transfer Printing is another method to improve metallization of HJT, and Risen is working on this technology. This approach is an alternative to screen printing, but it still uses a paste system. Here, the grooves are filled with paste which is then transferred on to the cell via laser. The benefit of this approach is that it can attain a very good aspect ratio of 1 and the method is non-contact, thus supporting very thin wafer processing.

Copper plating has not only been a long-term candidate for metallization of HJT cells, it has also been commercially available for a long time. As discussed in the previous editions of our report, it was mainly Dutch company Meco that was promoting a plating-based solution for metallization of HJT cells. Then, GS-Solar, a Chinese HJT producer that turned into an equipment supplier, also promoted plating aggressively until a couple of years ago, but later shifted to screen printing. However, the technology is now attracting new followers, and the leading equipment supplier is Maxwell.

The company is currently working on a seed and plate approach in which the copper seed layer is



Reinventing metallization: In the quest of improving metallization process, companies like Risen Energy are also evaluating new metallization techniques such as Laser Pattern Transfer Printing.

applied via sputtering, followed by masking the non-metallic area with photosensitive material and opening the contacts by exposure. Then, the electroplating of copper is accomplished simultaneously on the front and rear sides, followed by a photoresist strip and tin plating. The formation of metallic contacts is finished with annealing.

Maxwell is cooperating with several partners to improve the process and introduce plating in mass production industrial environment, according to Wolf. In his presentation, he also showed a table comparing different metallization approaches, in which plating has high potential for increasing efficiency and lowering metallization costs, while the CapEx, facility costs and yield losses are high (see table below). Maxwell also chalked out its commercialization plans – install the first pilot line in 2023, the first production line 12 months thereafter, and commercial offering in Q3/2024. Huasun's Zhou also foresees that plating might contribute to silver reduction as of 2024. Risen reiterates the benefits of copper plating – high efficiency with gain in Isc and FF through the use of pure copper-based contacts in place of low temperature cured pastes, and a reduction in finger widths to 18.1 µm compared to the 40.15 µm achieved with screen printing.

RENA, a longtime plating solutions provider, but not in favor of plating for HJT, has also started activities in this direction recently. RENA's Brunner, presenting the company's latest plating solutions at TaiyangNews HJT event, listed 3 reasons for changing their mind. The first one is that masking, which was complex, can now be done with silicon nitride. The growing interest in a plating solution for HJT, and fast and encouraging first results in early testing are the other 2 reasons. The company's solution is based on an inline platform. The wafer is immersed in electrolyte only on one side and is contacted from the other side. This way, the contacts are kept dry all the time. Biasing the cell from the rear side initiates the deposition in the structured surface on the front side. Brunner also showed details of a novel seed-and-plate approach developed by Swiss research institute CSEM that involves applying a thin, but still silver-based, seed layer. Then, the silicon nitride is deposited on the whole

09 **Metallization Technology Comparison**

MAXWELL

	MBB	Stencil MBB	NBB	Ag/Cu paste +Stencil NBB	Cu plating
BB paste(mg/w)	8	8	0	0	0
Finger paste(mg/w)	10	8	12	12	0
Paste price($/kg)	850	850	850	350	-
Paste cost($/w)	0.0153	0.0136	0.0102	0.0042	Total cost ~0.01
Eff gain	BL	+0.1%	BL	BL	+0.4%
Yield	BL	BL	BL	BL	2%~3% loss
Capex	BL	BL	BL	BL	~30% higher
Facility cost	BL	BL	BL	BL	~2X higher

Source: Maxwell

*Based on supply chain in China

Plating vs. Printing: While plating as an alternative to screen printing can reduce costs and improve efficiency, the CapEx, facility costs and yield losses still remain high.

area in a way that there is no dense deposition on the fingers. This allows direct copper plating, while the deposited dielectric prevents ghost plating (the undesired metal deposition on the open areas). This approach has worked straight away with RENA's tool platform and the adhesion and homogeneity of the resultant contacts are also up to the mark. This makes the concept ready to go, according to Brunner. He estimates the potential silver savings with this approach to be around 50%. RENA is still in the R&D phase with its plating solutions and is open to partnering for further development.

2.6 IV-Characterization

At the IV characterization station, HJT cells also require optimization. This is due to the fact that cell architectures such as HJT that have high open-circuit voltages requires longer voltage sweep times for precise and accurate measurement of their I-V characteristics. The details of HJT cell testing were covered in Sascha Esefelder's presentation, "High Throughput IV-Classification Of High Efficiency Silicon Solar Cells," at the TaiyangNews Virtual Conference on Solar Cell Production Equipment & Processing Materials, which was held on February 28, 2023 (see recording here). While PERC cells show no significant difference when cutting down the measurement time from 1 second to 20 milliseconds, HJT cells show a higher efficiency when the measuring time is reduced downwards from 500 milliseconds.

"250 milliseconds is already way too fast to get a reasonable measurement for HJT cells," said Esefelder. Understanding the discrepancy is made easier by the PC1D simulation with a 30-millisecond flash. The simulation demonstrated a bump at Pmpp in the reserve scan, measuring from Voc to Isc. This bump is manifested as higher cell efficiency that rises with shorter measurement times. This well-known phenomenon is often referred as high cell internal capacitance. According to a recent scientific study cited by Esefelder, a HJT module's measurement uncertainty ranges from one to 10% for measurement times under 100 milliseconds.

The industry standard for IV characterization, on the other hand, calls for a cycle time of 0.72 seconds, during which several tasks must be completed. Transporting the cell to the measurement position, closing the contacts, taking the measurement, opening the contacts, and then moving the cell away from the measurement position are the main steps.

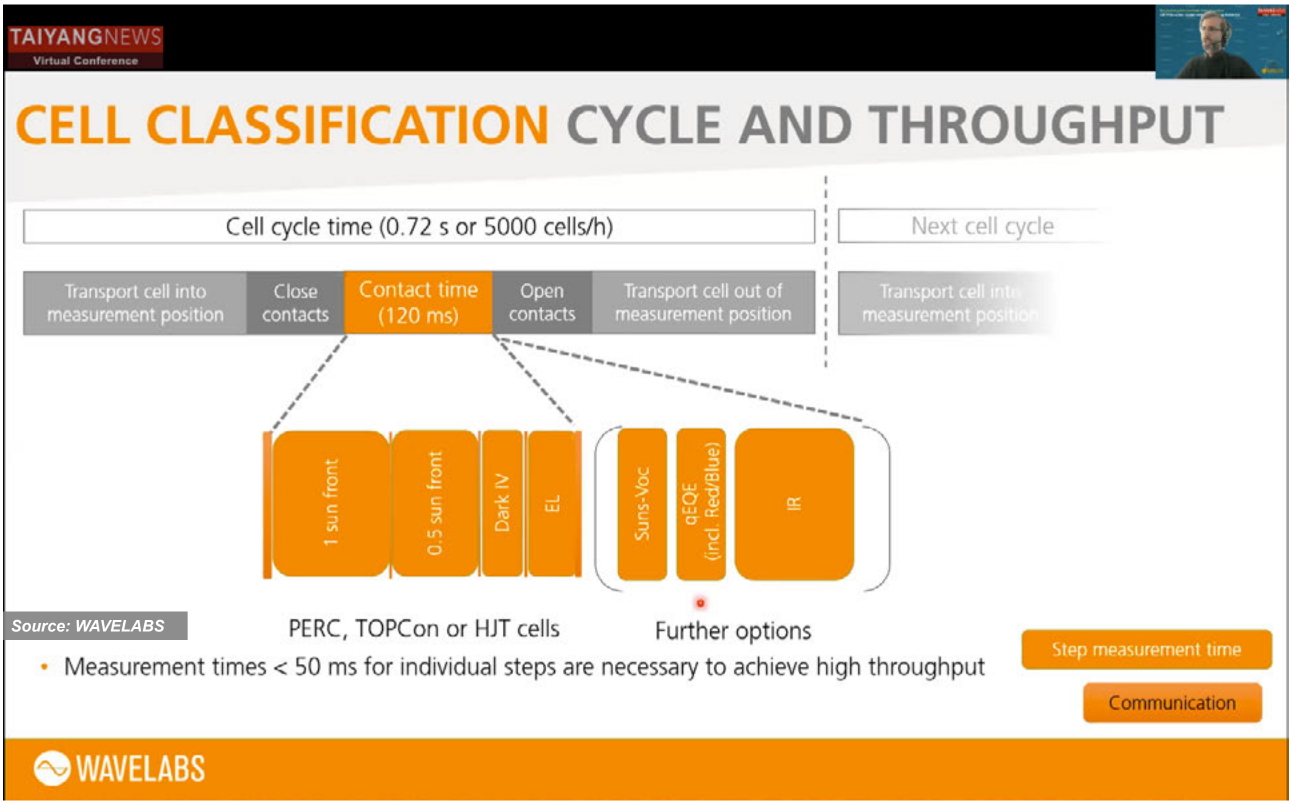
Taking out the time required for other steps leaves 120 milliseconds for the total measurement time. Additionally, a number of measurements must typically be completed during this period. These include the basic front side IV characterization, half-sun measurement from the front to determine the series resistance, dark-IV measurement to determine shunts and finally electroluminescence imaging for mapping the local defects, which now also became standard. There are also a few additional options such as Suns-Voc, quasi-EQE and IR imaging.

In order to facilitate all these, the measurement time has to be below 30 milliseconds, according to Esefelder, while HJT due to its high internal capacitance cannot support measurement times below 250 milliseconds. To bride this gap, WAVELABS developed the RapidWAVE algorithm, which drastically cuts the measurement times of HJT cells to just 20 milliseconds. The algorithm generates IV curves that closely resemble those from steady state measurements.

The SINUS-300 testing tool platform of the company not only features the function, but also enables measuring times spanning to a few seconds to cross check the accuracy of the fast measurement on the floor. The IV testing platform from WAVELAB also supports cut cell measurement, whether it be a 1/2 or 1/3rd, which is useful for HJT fabs that have begun implementing half wafer processing. Within a single flash, the cell slices are contacted and measured separately. According to Esefelder, the solution is also RapidWave compatible and simple to retrofit on-site.

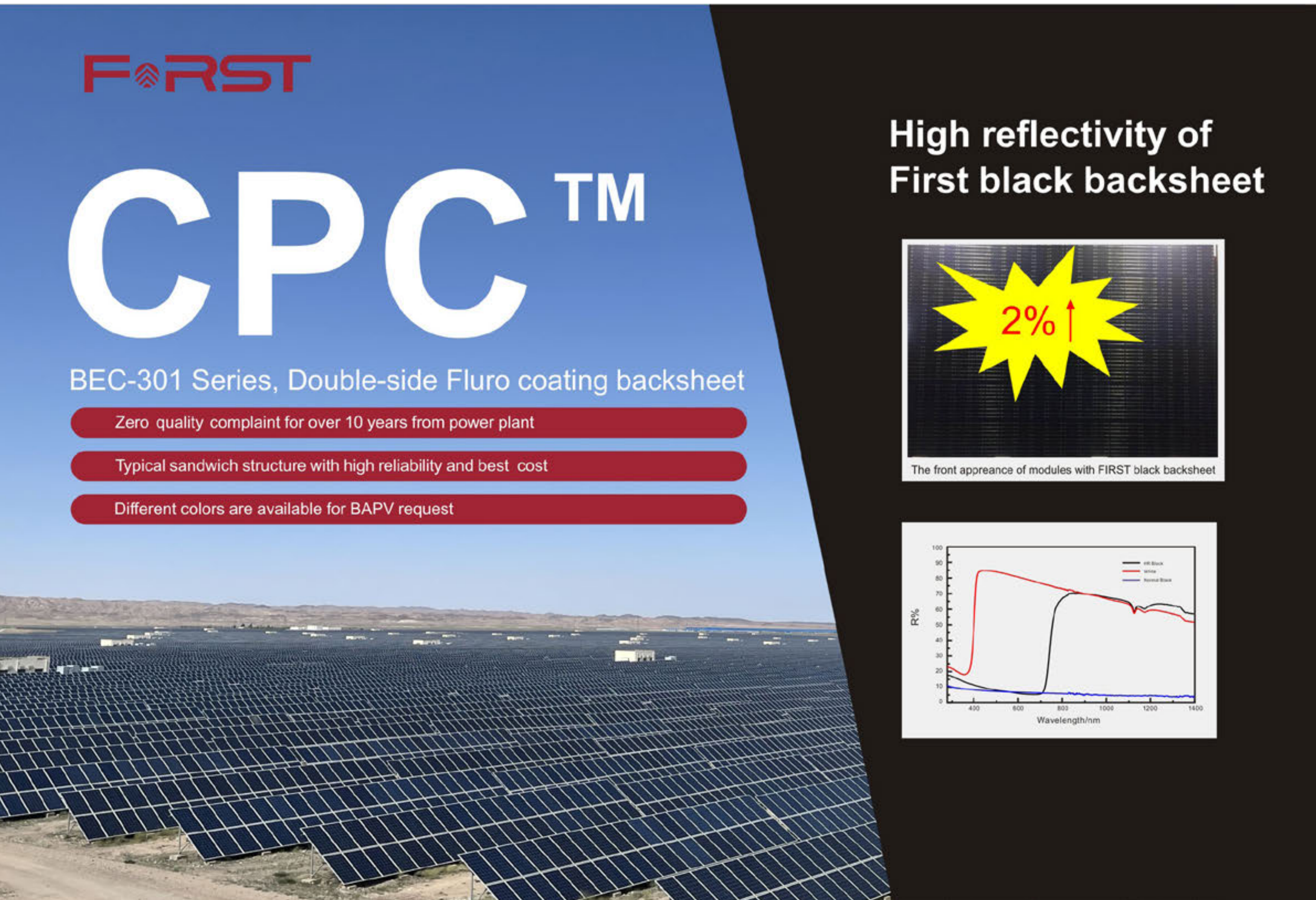
2.7. Light Soaking

Light soaking is the 3rd new step that is becoming a part of the standard process flow. The background is, upon the cell's exposure to operating conditions, the FF has been observed to decrease, leading to a loss in efficiency. However, current and voltage remain unaffected. A possible explanation for this degradation effect is that the oxygen enters the cell through the TCO and reacts with amorphous silicon to form amorphous silicon oxide, increasing the resistance as a result. To address this issue, the industry is following a so-called light soaking method, in which the cells are subjected to light and heat treatment. The step is expected to break the bond between silicon and oxygen and recover the losses completely.



In his presentation, HighThroughput IV-Classification Of High Efficiency Silicon Solar Cells, during the TaiyangNews Virtual Conference on Solar Cell Production Equipment & Processing Materials 2023, WAVELABS' Sascha Esefelder provided the breakdown of the classification of cycle time, which underscores the need to keep measurement time to less than 30 milliseconds.


FIRST
New Generation of EVA Film
EBISU
Free of Acid
Reduce acid to prevent crystalline solar cells from acidic corrosions
Help modules to maintain more reliable performances in humid and hot environment
Excellent protection for cells in damp heat environment
Excellent anti-PID property


FIRST
CPC™
BEC-301 Series, Double-side Fluro coating backsheet
Zero quality complaint for over 10 years from power plant
Typical sandwich structure with high reliability and best cost
Different colors are available for BAPV request
High reflectivity of First black backsheet
2%
The front appreance of modules with FIRST black backsheet
R%
Wavelength/nm

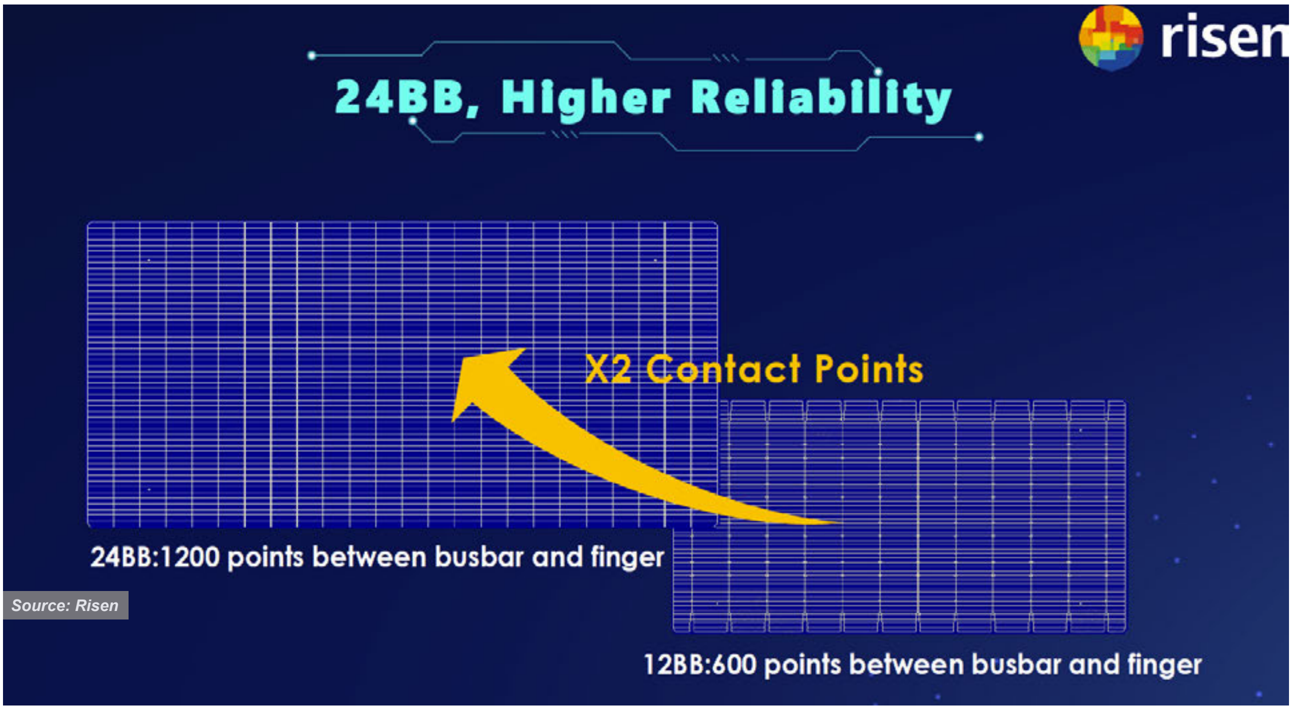
3. HJT Module Assembly

As for the changes required for HJT at the module level, it's more a matter of choice than compulsion. Taking interconnection as an example, HJT is not compatible with soldering in principle. However, most of the leading HJT makers are using optimized soldering, whereas low temperature supporting ECA based solutions are more popular outside China.

The main change required with soldering is a reduced temperature of less than 200 °C, and almost every stringing tool supplier offers low-temperature soldering support. Along with the temperature adjustment, the optimization of soldering material, the composition of the ribbon and the soldering method are just a few examples that require detailed readaptation to HJT, according to Risen. The company has spent a lot of time and effort on optimizing the HJT module making process. The 2 production equipment makers that offer ECA-based interconnection for HJT are Spain's Mondragon and Germany's teamtechnik. The details of ECA-based interconnection along with the optimization required for soldering have been discussed in previous reports and remain more or less the same.

The **number of busbars** topic discussed in the metallization section is implemented at the interconnection station. Risen tops the segment by being ready with a 24-busbar design. In addition to the savings on silver costs due to 'no busbars' and thin fingers, the design also brings a few other benefits. The more busbars, the shorter the distance between the contacts, thereby reducing the current density and power loss. It also increases the cell tolerance to microcracks and finger disruptions. The contact points between the busbar and finger increases by 2 times – 600 with 12-BB and 1,200 with 24-BB – which also increases module reliability, according to Risen's Yang. Huasun is already offering a 15-busbar based module and is evaluating options to increase the busbar count to 18 and beyond.

When it comes to **module BOM**, hydrophobic HJT requires an **encapsulation** solution that supports low moisture ingression rate; and equally important is the optimization of encapsulation material from a TCO compatibility standpoint. The polyolefin (POE) and coextruded structure of EVA-POE-EVA (EPE)



Source: Risen

Busbars galore: Increasing the number of busbars not only improves electrical performance but also reliability. Shown here is the 24-busbar layout from Risen.

offered by leading encapsulation material suppliers can meet these demands, especially in glass-glass modules, while a low-cost solution is still under evaluation for glass-backsheet configuration. EPE is currently the most widely used encapsulation solution for HJT.

Then, encapsulation material makers have developed a somewhat disruptive solution, specifically for HJT. To negate the absorption losses in amorphous silicon layers and TCO, especially the UV portion, Cybrid and Hangzhou First, in a coop effort, have developed a wavelength transfer film that converts the UV light into blue or red light. This approach has the potential to increase the module power by about 1.5%. While the technology can be adapted to any polymer base, since EPE is widely used, the solution is predominantly offered with EPE, but not limited to.

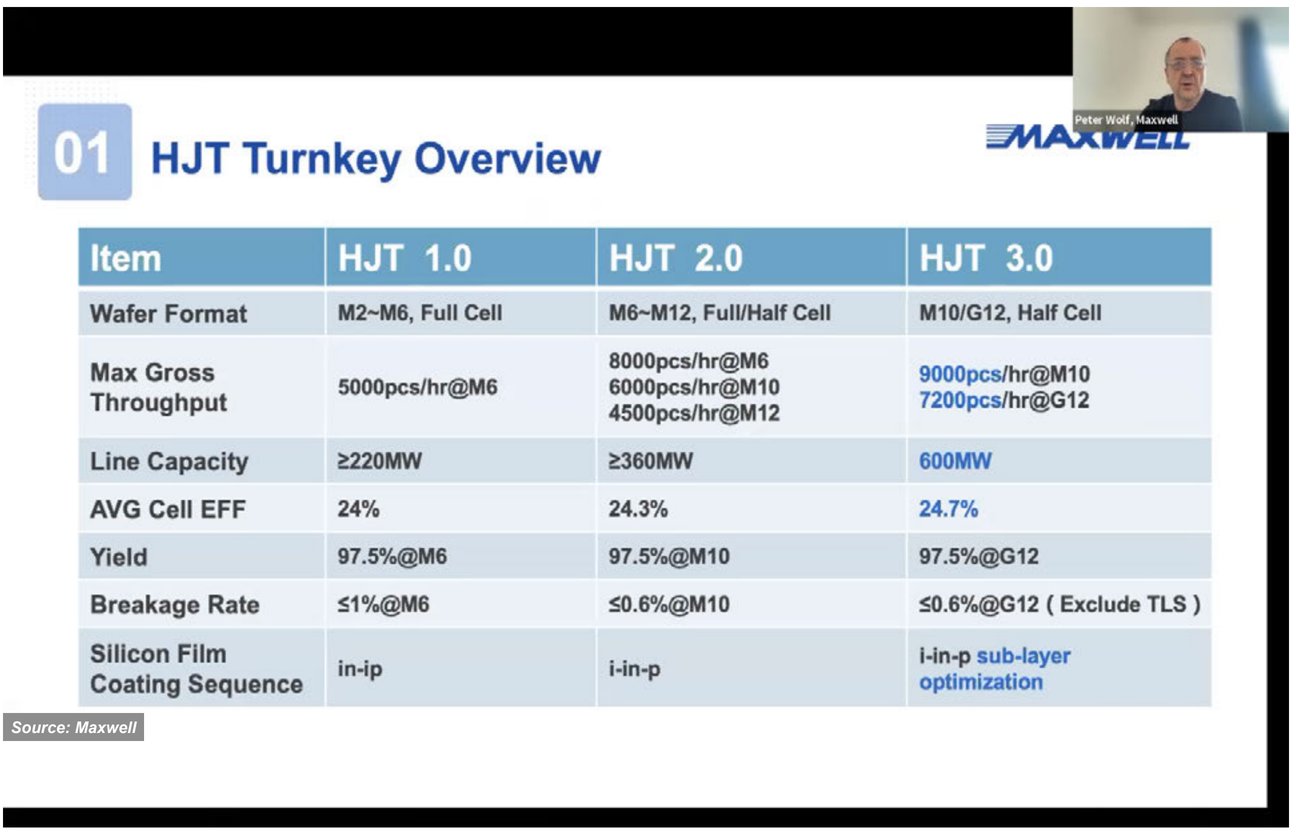
Within the **backsheets** segment, suppliers are increasingly bringing in high WVTR barrier products without using aluminum. While inserting a sheet of aluminum was a practice used to reach high barrier properties in the past, backsheet makers are now offering aluminum-free high barrier backsheets which can also be opted in transparent variants to be compatible with bifacial technology. Italy's Coveme, for example, launched one such product in mid-2022, while a few others are also offering similar polymer compositions. The encapsulation and backsheet solutions suitable for HJT are being discussed in detail in the latest **TaiyangNews Market Survey on Backsheets and Encapsulation Materials 2022/23**, which can be downloaded for free HERE.

4. Total Line Solutions

In addition to selling production equipment for individual process stations, a few equipment vendors are also offering turnkey solutions. These companies, typically having the in-house knowhow for key equipment used in HJT (PECVD and PVD), have extended their product portfolio or cooperate with other tool suppliers. Take **Maxwell**, which was originally a screen printer maker, and is now cooperating with YAC from Japan for wet-chemical benches and offering an end-to-end production solution for HJT under one roof. The company's solution also includes automation, MES systems and even MBB-based stringing tools for module manufacturing.

Highlighting the automation solution of the company, Maxwell's Wolf said that the specialty of its solution are the handling tools provided with additional FFU chemical filters. This facilitates much better clean room standards of Class 1,000 inside the automation as well. The feature turns out to be very beneficial when the wafers are transferred from texturing to PECVD and unloaded from there to CVD. Any level of contamination during these 2 handling steps has a significant impact on the final efficiency and line yield. The automation is capable of handling half wafer formats of M10 and G12 sizes.

H2GEMINI is also offering a turnkey line. While it offers the PECVD along with its specially designed tray-less transport automation, the company has teamed up with exateq for wet-chemistry, and with Applied Materials for the backend line. As for PVD, the company is partnering with an OEM. GS-Solar is yet another equipment maker that is offering turnkey solutions. The below table summarizes the key equipment vendors for all steps of HJT processing and the turnkey solution providers.



Item	HJT 1.0	HJT 2.0	HJT 3.0
Wafer Format	M2~M6, Full Cell	M6~M12, Full/Half Cell	M10/G12, Half Cell
Max Gross Throughput	5000pcs/hr@M6	8000pcs/hr@M6 6000pcs/hr@M10 4500pcs/hr@M12	9000pcs/hr@M10 7200pcs/hr@G12
Line Capacity	≥220MW	≥360MW	600MW
AVG Cell EFF	24%	24.3%	24.7%
Yield	97.5%@M6	97.5%@M10	97.5%@G12
Breakage Rate	≤1%@M6	≤0.6%@M10	≤0.6%@G12 (Exclude TLS)
Silicon Film Coating Sequence	in-ip	i-in-p	i-in-p sub-layer optimization

Source: Maxwell

Turnkey: Leading equipment makers for HJT are also offering turnkey solutions; here are the details and roadmap of Maxwell.

Equipment Vendors Active in Supplying Tools for HJT					
Company	**Wet-chemical**	**Core layer deposition**	**TCO deposition**	**Screen printer**	**Turnkey**
Applied Materials		✓		✓	
Exateq	✓				
GS-Solar		✓	✓		✓
H2GEMINI		✓	✓		✓
Ideal Energy		✓			
INDEOtec*		✓	✓		
Maxwell		✓	✓	✓	✓
Rena	✓				
S.C. New Energy	✓	✓	✓		✓
Singulus	✓		✓		
* lab scale; ** though OEM					

Source: © TaiyangNews 2023

Expanding supplier base: HJT equipment supply now has a breadth of players offering separate tool sets and turnkey solutions.

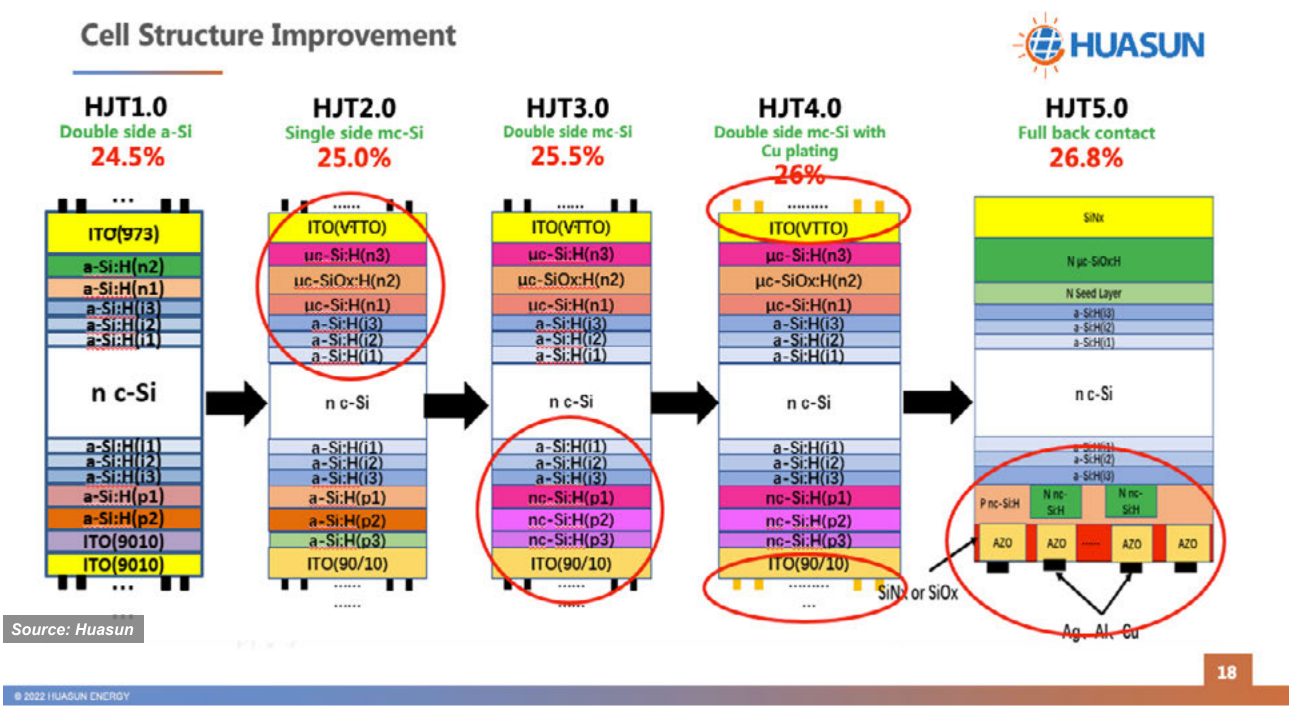
5. Performance of HJT Devices

One of the most important attributes of HJT as a technology is its high cell efficiency. This is facilitated by the superior passivation quality of the cell structure that results in high Voc. PV producers, equipment makers and research institutes have announced different efficiency levels for their HJT cells. Several module makers have also introduced various configurations of HJT modules for use in different applications.

5.1. Cell

Speaking of the progress in cell efficiency, especially during the latest commercialization phase of HJT in China, Hanergy is one company that deserves a special mention. A yesteryear pioneer in the domestic HJT segment, the company was also the first among the Chinese HJT stakeholders to attain world record efficiency under the leadership of Xixiang Xu. Hanergy's last best efficiency of 25.11% was announced at the end of 2019. When Hanergy wound up its activities, the HJT team practically split to join 2 companies – LONGi and Maxwell, while Xu himself joined LONGi. This also probably explains why LONGi and Maxwell are at the top of the game in announcing record efficiency levels. It is under the leadership of Xu that LONGi went past Kaneka's 5-year-old world record for silicon solar cell efficiency, achieving 26.81% with its HJT solar cell. Impressively, this was achieved with an 'HJT only' cell, whereas Kaneka's cell was a hybrid architecture that combined HJT with IBC (HBC). LONGi also boasts that the world record efficiency for a silicon solar cell is now owned by a Chinese company for the first time, 68 years after the first silicon solar cell was produced by Bell Labs in the US. While Kaneka's record cell was smaller in size at 79 cm^2, LONGi says its latest efficiency record has been established on an unspecified "larger wafer size." In fact, even before splashing out the news of this latest world record cell, LONGi had also attained 2 more certified efficiency levels of 26.7% and 26.75% that were simply archived.

LONGi said that these record levels were a result of optimizing several parameters, such as improving the n-type doped microcrystalline silicon layer



HJT Evolution: At the TaiyangNews Conference, Huasun showcased the latest generations of HJT structures and provided an overview of their potential efficiency levels.

for enhancing current collection, a new intrinsic layer structure developed to enhance passivation performance, and optimized TCO.

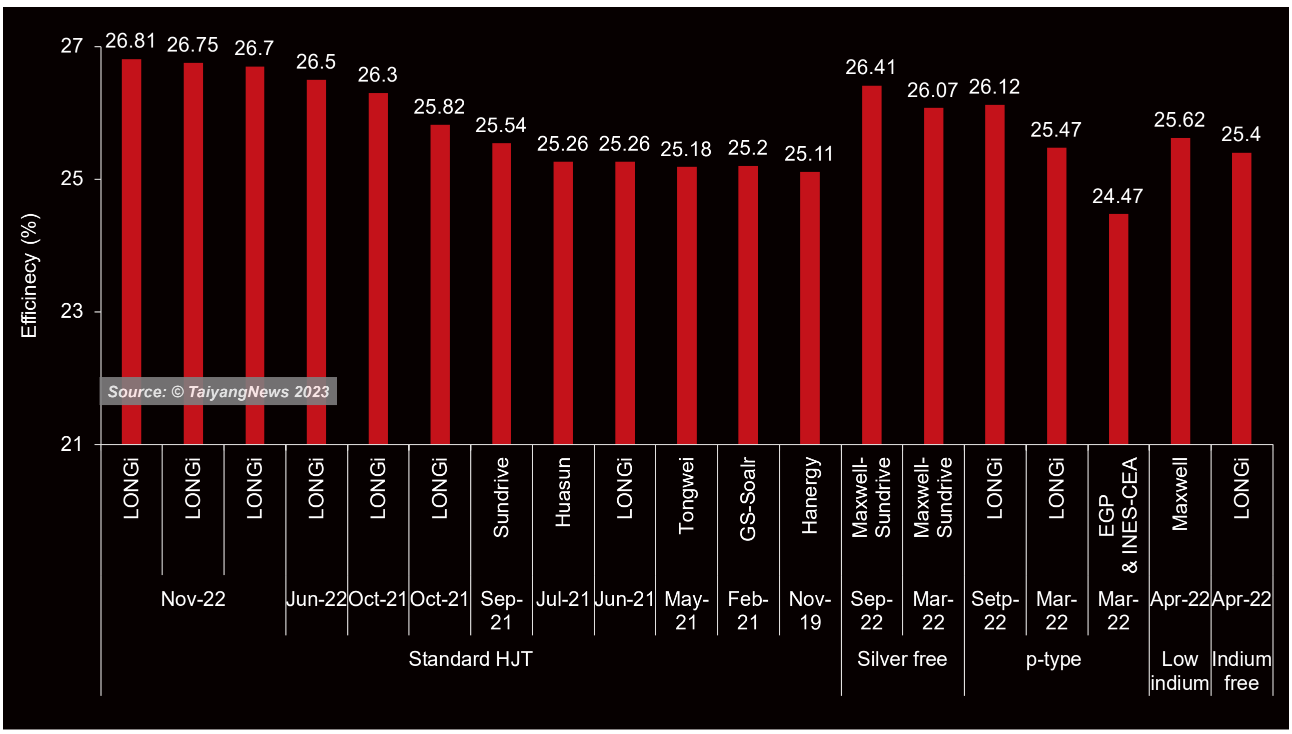
LONGi stood at the top in the HJT segment even before this feat, with its previous best efficiency of 26.5%. While the company has not contributed much in the way of commercializing the technology, it did motivate several companies to find other avenues. As can be observed with efficiency announcements in the recent past, companies are pursuing record efficiency levels under different categories such as silver-free, indium-free, low indium and p-type, which are commercialization-relevant subjects. This indicates that there are multiple options for cost reduction. One such notable announcement was from the partnership of Maxwell and Australia's Sundrive reaching 26.41% for a silver-free solar cell.

When it comes to real-time production efficiencies, Huasun's Zhou says that the best cell batch from the production lines based on HJT2.0, which is also implemented in the company's 2 GW phase II factory, has an average efficiency of 24.92%; the best cell even hit 25.21%. At an R&D level, also with HJT2.0 and M6 size, the average was 25.45% with the champion cell reaching 25.61%. Huasun plans to introduce HJT3.0 (microcrystalline on both sides) in 2023, which it expects to bring a further 0.5% efficiency boost. The next efficiency gain is expected with copper plating on both sides and followed by full back contact architecture. Zhou also presented the efficiency roadmap of the company (see the below slide).

Risen's highest HJT cell efficiency is 25.5%, achieved in Q4/2021 and realized on a 120 µm wafer slimmed down to 100 µm after texturing. The cell features microcrystalline silicon on both sides.

GS-Solar says its customer has reached an average efficiency of 25.2% for bifacial HJT cell using microcrystalline silicon, while the champioin cell of the company attained 26%. The company aims to reach 26.2% in mass production by 2026 and Zhang list the key techniques that would enable the progression in this direction as employing microcrystalline on both sides, new TCO materiel's,

Certified Record HJT Cell Efficiencies



Many ways lead to Rome: Companies are exploring new categories, such as p-type, silver-free, indium-free and low-indium, to achieve record efficiencies that are not only noteworthy for the chronicles but also relevant for mass production developments.

new types of silver pastes, new metal grid pattern approaches, ultrafine copper plating and wafer of high quality and lager size.

Maxwell started with 24.4% with its complete line, and has now introduced already the nanocrystalline doped layer on the n-side to achieve efficiencies of 25% in mass production. The company is now evaluating different possibilities with metallization, which brings in benefits both on the efficiency as well as the cost front. In parallel, Maxwell has also been piloting the p-type nanocrystalline on the rear side, which boosts the efficiency to over 26%. “Our target is to achieve an average mass production efficiency of 26% by end of 2023,” says Wolf.

The industrial efficiency for HJT cells in China has surpassed 25% in general.

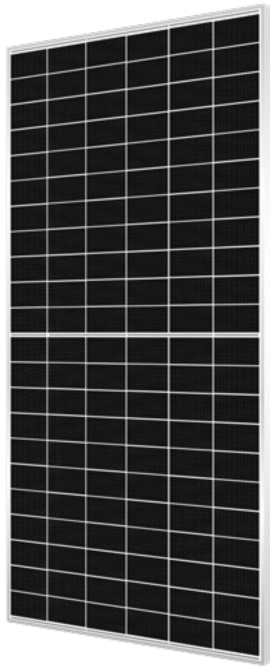
5.2. Module

All the efforts put into improving cell efficiency eventually also show up at the module level. While talk about top module efficiency is not so common, Risen highlighted that it broke the record 4 times straight. The latest being as recent as February 13, 2023, when the company announced that it attained a certified efficiency of 23.89%. In comparison, the highest module efficiency announced for crystalline silicon is still at 24.4% by Kaneka. Risen’s record large-size HJT module has a power rating of 741.5 W. As for commercial offerings, it is in the process of commercializing a top-notch product called Hyper-ion that combines the most advanced features of the HJT segment. The key attributes according to the company are listed below:

- Uses G12 half-cut wafer format, 120 μm wafer thickness (saves material).
- Patented 24-busbar design: The cell design consists of no busbars that considerably reduces silver consumption, while supporting a 24-busbar interconnection layout at the module level.
- Low Ag content: Uses less pure silver, roughly 10 mg/W.
- Steel frame: Carbon footprint is reduced by 77% compared to aluminum-frame modules.
- High energy yield: Low temp coefficient and high bifaciality of 85%.
- Low degradation: No LID and PID issues.
- Superior electrical parameters: Rated power of 700 W, cell efficiency of 25.5% and 22.5% module efficiency.

The world’s largest cell manufacturer, Tongwei Solar is also developing a high-power 720 W HJT module with 23.2% efficiency.

However, Risen record module is not yet reflected in the product portfolio on its website, and the data sheet for Hyper-ion series is still marked as ‘Draft,’ meaning it is not yet available commercially, which explains its absence from our latest Top Module list in March 2023.



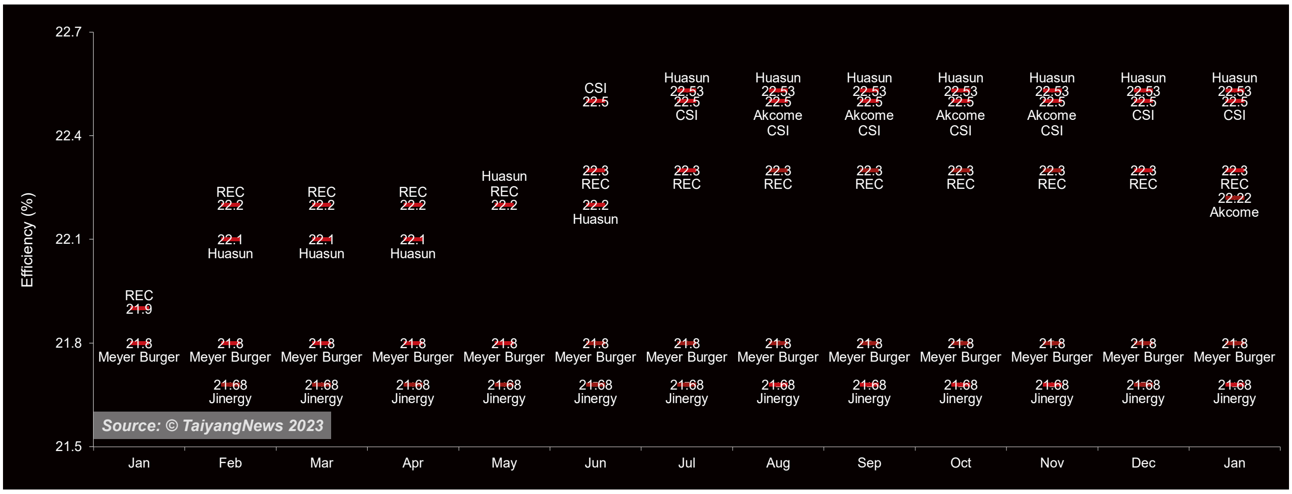
Source: Huasun

A bunch of improvements: The latest Himalaya module series from Huasun uses several advanced approaches – pre-cut wafer processing, 15 busbars and efficiency of 22.5% and a power rating of up to 700 W.

The products from other leading manufacturers as well as the progress of HJT modules are reflected in the different monthly editions of the TaiyangNews Top Modules List. When the survey was started in January of 2022, there were only 2 companies that were offering high efficiency HJT modules – REC and Meyer Burger with 21.9% and 21.8%, respectively. In the very next month, not only did REC increase the efficiency to 22.2%, but Huasun (22.1%) and Jinergy (21.68%) also made it to the Feb. 2022 listing. Jinergy’s product all along represented the lower efficiency level of HJT segment. In June, Canadian Solar made its entry with a 22.5% module. In the immediate next edition, Huasun's high power Himalaya series found itself in the list with an efficiency of 22.53% and a power rating of 700 W, which still remains the highest. The module uses cells made from pre-cut wafers, and is made up of 132 such cells. It uses the 15-busbar interconnection layout. Then, the subsequent August listing included the Hi-Chaser series from Akcome with a power of 700 W and 22.5% efficiency.

As to the application of these modules at the **system level**, there is not big news. HJT, having a low temperature coefficient of –0.26%/°C and the highest bifaciality, is expected to perform well in real-world conditions. Given its high costs, the technology has been mainly promoted for the premium rooftop segment. Interestingly, HJT module producers have recently started launching very large modules with power ratings of 700 W, like Huasun – and these panels are aimed at the large-scale utility segment. In August 2022, Meyer Burger signed a supply agreement in the US to deliver 3.75 GW between 2024 and 2029 for the client's large-scale projects.

HJT Solar Module Efficiency Range Developments From 1/2022 - 1/2023



Tracking HJT's progress: TaiyangNews TOP MODULES ranking reflects the growing commercial activity in HJT, from only 2 models featured in early 2022 to six high-efficiency products in January 2023.

6. Commercialization and Capacity

HJT as a technology has never fallen short when it comes to attracting interest from new as well as established PV manufacturers. Most of the tier 1 companies, including LONGi, Canadian Solar, Aiko and Trina, have already installed pilot lines. However, when it comes to commercial activities, Huasun is the pioneer of the segment.

Founded only in July 2020, **Huasun** has quickly increased its footprint in the commercial HJT segment with an installed capacity of 2.7 GW as of the end of 2022. The company installed and commissioned its first fab with a capacity of 600 MW that was basically designed for the M6 wafer size. The Chinese company has also successfully finished the installation and commissioning of a Phase 2 facility with a capacity of 2 GW that runs the G12 size wafers. Its latest fab is designed for processing pre-cut wafers and is capable of implementing the so-called HJT2.0, i.e., using doped microcrystalline silicon on the emitter side. Both the facilities are teamed up with corresponding module production facilities as well. Zhou presented the company's mass production data for the phase 1 facility at the TaiyangNews Conference. Huasun started manufacturing with M6 wafers in Q2/2021 processing above 30,000 cells per day, then ramping up to more than 150,000 by end of Q4/2021, while the cell yield was increased from about 95% to over 97%. As part of the continuous optimization of production tools all along the line, especially the process time, the throughput has also been increased. As a result, the facility's capacity has been increased to 890 MW by the end of 2022. At the same time, yield has also been improved to 99.4%.

Risen Energy has been producing HJT modules for 3 years now and has built a 400 MW pilot line. The company's Sieger HJT Series, its flagship module offering at the time, claimed top honors for HJT shipments in 2020 and 2021. In 2022, Risen upgraded its pilot line for G12 half wafers and increased the capacity to 500 MW with the launch of its Hyper-ion series. As mentioned above, this module series combines several latest technological developments in the HJT segment. Risen received the world's first TUV certification for its G12 high efficiency HJT module in August 2022, said Yang.

He also presented the company's ambitious future expansion plans – currently building a 5 GW HJT cell-and-module fab with a target to produce the first cell in H1/2023, and to add 10 GW on top for a total of 15 GW by the end of 2023.

Tongwei is another Chinese company that has also moved into high-volume HJT manufacturing. In addition to its 2 pilot lines, of which one is designed to handle M2 and the other G12 wafers, the company has successfully installed and commissioned a 1 GW HJT cell factory, expanding its capacity to 1.2 GW. It is selling these cells to module assemblers. The company has also built an advanced metallization R&D lab, primarily for HJT. It is working on all the methods and means to improve the efficiency and reduce costs as part of its R&D efforts, including half wafer processing, using nanocrystalline silicon layers on both sides, copper plating and thinner wafers.

However, there are many companies in China looking into investing in solar cell production, increasingly also into HJT production – development that are covered in the China PV Snippets of our daily Newsletter. In Feburary, for example, jewelry enterprise MINGR announced plans to invest RMB 10 billion ($1.47 billion) in the construction of a solar facility in Keqiao. In the first phase, a 10 GW TOPCon solar cell will be built, while in the second phase, a 6 GW TOPCon cell facility and 4 GW HJT cell facility will be built. Or electrical machinery and equipment manufacturer Xinrui Optoelectronics, in February 2023 said via WeChat that its new high-efficiency photovoltaic cell facility has begun construction in Gaoyou City. Once fully operation, it will have an annual output of 12 GW high-efficiency TOPCon and HJT cells.

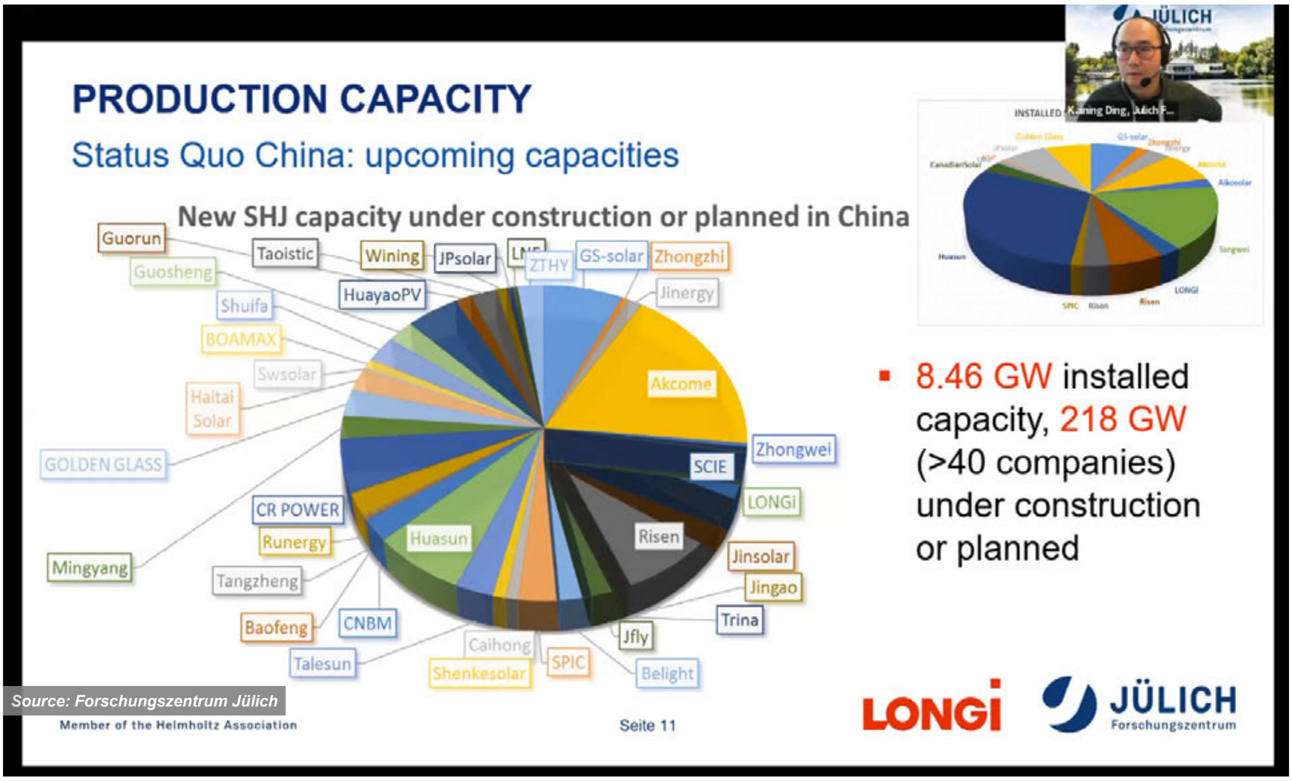
HJT is the most sought after PV technology platform in bringing manufacturing back to **Europe**. **Enel Green Power** is building the continent's largest HJT module fab of 3 GW in Italy with support from the European Commission. The facility is scheduled to be fully commissioned by July 2024, with initial production of 400 MW slated to start from September 2023. Today, the largest European HJT cell/module manufacturer is **Meyer Burger**, which produced 321 MW in 2022, and said in January 2023, that it expects to produce between 1 GW and 1.2 GW in 2023 as guided earlier. Meyer Burger is ramping up its second line in the first quarter and plans to start ramp-up of the 3rd line in Germany in Q2/2023, expecting a nominal production capacity of around 1.4 GW.

In Dec. 2022, Russian solar cell and modules manufacturer **Hevel Group** said its 350 MW annual production facility was upgraded to handle larger M6 wafer sizes and solderable metallization layout. The cells now sport mass production efficiency of 24.5% with 0.26%/°C temperature coefficient. Hevel's majority stakeholder, Ream Management has been also investing in Unigreen Energy to build its EnCore Gigafactory, a 1.3 GW silicon n-type monocrystalline ingots and wafers fab, and 1 GW HJT factory in Russia's Kaliningrad region. It was planned to be ramped up in late 2022 but on the website it says now that the 1 GW HJT cell/module facility will start production in 2023.

Singapore based **REC** has put its plans for a European HJT factory on hold for the moment while its parent company Reliance is quickly proceeding with its 4.8 GW integrated HJT module fab in India.

HJT is also expected to play an important role in attracting PV manufacturing to the US as part of the country's Inflation Reduction Act of 2022. Spurred by the IRA, in November 2022, Italy's Enel Group through Enel North America has announced plans to establish a bifacial heterojunction solar cell and module manufacturing fab in the US with 3 GW annual capacity initially, to be expanded to 6 GW. Meyer Burger is targeting initially 400 MW cell/module capacity, and eying later expansion to 1.5 GW.

When it comes to actual installed production capacity, FZJ's Ding, presenting at the TaiyangNews Conference, said that while the installed capacity for HJT is about 8.46 GW in China, the announcements, including plans and facilities under construction, add up to an unbelievable 218 GW.



High interest: HJT has never fallen short when attracting announcements, as summarized by FZJ's Ding at the TaiyangNews HJT event. While HJT manufacturing capacities in China totaled to 8 GW, announcements including plans and factories under construction add to as much as incredible 218 GW.

金石能源
GOLD STONE

LARGEST CAPACITY WITH ADVANCED TECHNOLOGY PECVD SYSTEM

Single 1GW production capacity HJT cell line of GS-SOLAR

PECVD EQUIPMENT	
GS generation	PECVD-7.0
Single capacity	1GW
Uptime	90%
Chamber dimension(≈)	3.5m*3.5m
Tact time（S)	51s
Carrier（210Half)	13*26
Throughput(pcs/h)	23,859
Applicable wafer dimensions	M6、M10、M10 half format、M12、M12 half format

The largest vacuum chamber of HJT PECVD

13.56MHZ

Using 13.56MHz RF，plasma damage free & optimal uniformity for large chamber

Workshop with smaller area, lower factory construction and facility investment

Superior design of hollow carrier，energy saving 20%

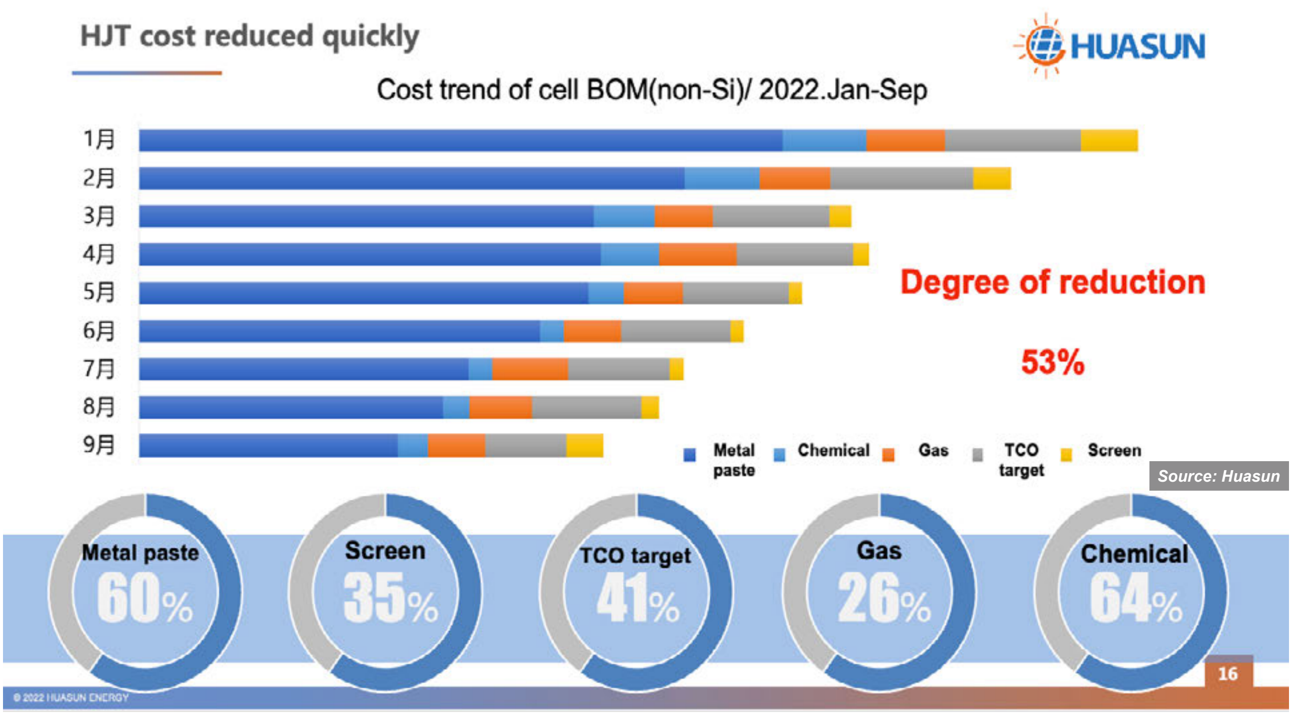
GS-SOLAR Group
GOLD STONE (FUJIAN) ENERGY COMPANY LTD.
sophia@goldstonesolar.com

7. Costs

As we have discussed throughout this report, there has been considerable progress in HJT. If there is one limiting factor, it is simply costs – both CapEx and OpEx.

As for equipment CapEx, it is still high at 350 to 400 million RMB/GW as of the end of 2022, seeing only a slight reduction from a level of 400 million in 2021. One effective way to reduce equipment costs is to improve the throughput. Equipment makers have been constantly optimizing their tools on this account. On the other hand, tool suppliers have done a remarkable job in optimizing production equipment all along the line, first to handle larger wafers and then to handle half wafers, and all without losing on throughput. The target is to attain an equipment CapEx of 250 million/GW.

As for the OpEx, Huasun's Zhou says that non-silicon costs in HJT cell production were reduced tremendously during the first 9 months of 2022. At the TaiyangNews Conference, he presented 5 important aspects of cell production where cost reduction has been achieved – metallization pastes by 60%; 35% in screens; TCO targets by 41%; gas by 26% and chemicals by 64%. All of these put together account for an overall cost reduction of 53%.



Cost reduction: Huasun reported a significant and rapid decline in HJT manufacturing costs – over 50% reduction during the first 9 months of 2022.

8. Conclusions

As TOPCon has been establishing itself as the main successor to PERC, a few companies are betting directly on HJT, while most of the major players continue at least serious R&D in the HJT field. Why? Costs are the single biggest bottleneck for HJT. However, there are a handful of avenues for optimization – and here a lot has happened over the last few months.

Starting from the wafers, which account for almost half the costs of a cell, the segment has seen some significant developments. The use of gettering is already lowering the high barrier set for wafer quality. The next area with the highest potential to reduce costs is wafer thickness. There are some companies that are already working with 130 µm wafers, and have plans to reduce it further. Given its symmetrical structure, HJT intrinsically supports thin wafers. It has also been well demonstrated that this cell technology can be implemented on wafers as thin as 100 µm without incurring much efficiency losses. In this context, Huasun has developed a half brick cutting process, which eases the production of 100 µm wafers.

Silver is the second biggest contributor to costs. According to Huasun, using SMBB, silver consumption was initially reduced to 140 mg/wafer, and adopting a metal mesh reduced it further to 120 mg/wafer. Silver-coated copper has brought in the next level of reduction, down to 100 mg/wafer. The last leg here could be zero busbars, which Risen is already implementing, where silver consumption can be reduced to around 70 mg/wafer. Then, it's about going completely silver-free, with copper plating. In fact, plating is seeing a flurry of activity. Maxwell is not only making progress with its plating technology, as is evident from its record efficiency levels announced from time to time, according to its roadmap it wants to commercialize plating in less than 2 years' time.

TCO comes in next in terms of costs – and there has been significant optimization in target utilization, which remains an ongoing effort. Case in point, Huasun achieved a reduction of 41% in TCO target related costs over a period of about 9 months. As to the concerns with indium's limited reserves and subsequent high prices, experts opine that such a critical situation is unlikely. Even if it does arise, the industry is prepared; approaches like stacking ITO with AZO or SiNx, which can reduce indium consumption by up to 85%, are already under evaluation.

The key aspects for manufacturing as a whole are: maintaining yields above 98.5%, equipment uptime above 90% and reducing the consumption of utilities. As for production equipment related costs, in addition to increasing throughput, the HJT segment is also attracting newcomers, which should help bring the prices down further.

A very effective means of reducing costs, though indirect, is improving the efficiency. As it was reflected at the TaiyangNews High Efficiency Solar Conference in November 2022, not only PV manufacturers, but also equipment makers, have established roadmaps to increase cell efficiency much further. Huasun, for example, presented its roadmap with 5 generations of HJT technology (HJT1.0 to HJT5.0). The Chinese HJT maker started at 24.5% in 2021 and attained an efficiency of 25.2% in 2022. The target for 2023 is to reach 25.5% with HJT3.0 through the use of microcrystalline doped layers on both sides that ultimately leads to a module power of 730 W. In a year from there, it aims to reach 26% cell efficiency and 745 W module power with the use of plated contacts. The next step to go beyond 26% is to fuse the back contact structure into HJT, and finally introduce perovskite tandem solar cells into the production line by 2025.

Independent from the cell level, approaches such as light conversion encapsulation films and reflective ribbons also help boost module performance. From going into high volume production in 2022, as highlighted in our previous report, to now focusing on reducing costs, HJT has indeed come a long way. But to leave its prime segment rooftop niche further improvements are needed.

CYBRID
Valued by Innovations

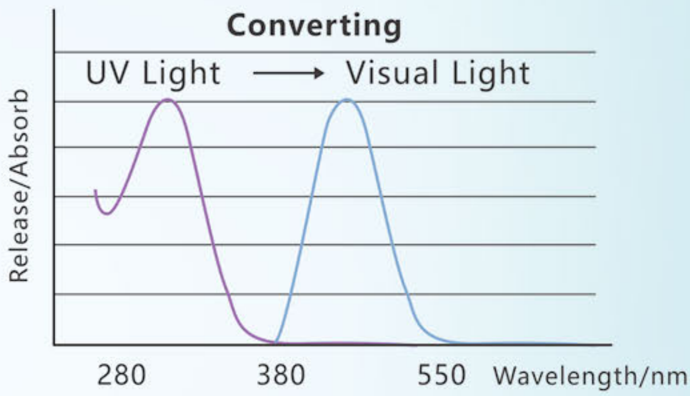
Raybo™ Technology Wavelength Converting Film For HJT Module

Power Boost for HJT module

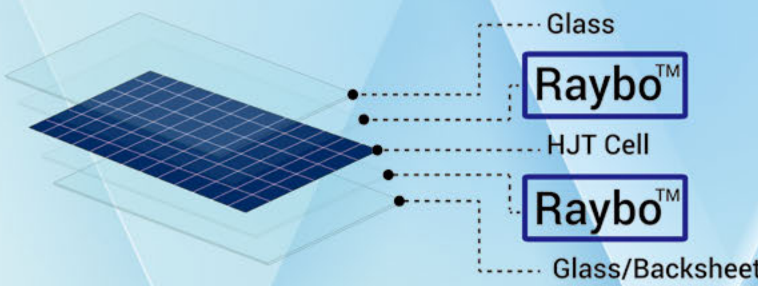
1.5% POWER BOOST FOR HJT MODULE

50 YEARS EFFECTIVE

Wavelength Transfer Principle:



Encapsulant For HJT Module



Outdoor Application

CYBRID TECHNOLOGIES INC.

CYBRID

--Polymer Material Solutions provider for PV
--EPE &POE Tier One Supplier
--Backsheet Shipments more than 250GW

Contact:sz-cybrid@cybrid.net.cn
Website:www.Cybrid.com.cn

TAIYANGNEWS
ALL ABOUT SOLAR POWER

9 783949 046162